U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-296 841

Menomonee River Basin, Wisconsin; Summary Pilot Watershed Report

International Joint Commission-United States and Canada, Windsor (Ontario)

Prepared for

Environmental Protection Agency, Washington, DC

4 May 78

PB 296841

REFERENCE GROUP
S POLLUTION
E ACTIVITIES

INTERNATIONAL JOINT COMMISSION

SUMMARY PILOT WATERSHED REPORT MENOMONEE RIVER BASIN, WISCONSIN

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U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

0272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. IJC/PLUARG -79/14	2.	3. Recipient's Accession No. PB296841
4. Title and Subtitle: Menomonee River Basin, Wisconsin summary pilot watershed report			5. Report Date: May 1978
			6.
7. Author(s): J.G. Konrad, G. Chesters, K.W. Bauer			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: PLUARG Task C - International Joint Commission, Great Lakes Regional Office, 100 Ouellette Avenue, 8th Floor, Windsor, Ontario N9A 6T3			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address: PLUARG - International Joint Commission, Great Lakes Regional Office, 100 Ouellette Avenue, 8th Floor, Windsor, Ontario N9A 6T3			13. Type of Report & Period Covered: Summary technical
			14.

15. Supplementary Notes

Funded through United States Environmental Protection Agency

16. Abstract (Limit: 200 words)

This document describes the methodology and reports the conclusions and recommendations for remedial measures resulting from the Menomonee River Basin studies.

Pollutant contributions from land use activities to surface and groundwater, inputs from atmospheric sources and the impact of changing land uses on pollution loadings are reported. Parameters emphasized are suspended sediment, total phosphorus and lead.

Simulated unit area loads were developed for twelve land uses (feed lots, wetlands, woodlands, park and recreation, row crops, industrial, commercial, high, medium and low density residential, land under development, and pastures and small grains). A relative hazard scale (logarithmic) was established.

A discussion of the physical characteristics and of the composition and particle size distribution of soils and bottom and suspended sediments in the basin is presented. The importance of this information in the development of remedial management strategies is presented and an evaluation of particle size distribution and dispersibility of sediments is used to shed some light on pollutant availability in the river and lakes.

17. Document Analysis a. Descriptors

Nonpoint pollution, water quality monitoring watershed studies, land use, sediment, lead, phosphorus, pollutant loadings, pollutant transport

b. Identifiers/Open-Ended Terms

PLUARG - IJC

c. COSATI Field/Group

18. Availability Statement: Unlimited through NTIS	19. Security Class (This Report)	21. No. of Pages: 87
	20. Security Class (This Page)	22. Price: PC A05/MF A01

(ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

MENOMONEE RIVER

PILOT WATERSHED STUDY

SUMMARY PILOT WATERSHED REPORT

Submitted to

International Joint Commission

Reference Group on Pollution from Land Use Activities

by

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1. ACKNOWLEDGEMENTS TO SPONSORING AGENCIES

The personnel of the Menomonee River Pilot Watershed Study wish to express their sincere thanks to the U.S.-Canada International Joint Commission, its Windsor Office Personnel and the Pollution from Land Use Reference Group for the high quality of organization of the Program devoted to an examination of the implications of land use and land use practices on the Great Lakes. A special debt of gratitude is owed to the U.S. Environmental Protection Agency for financial support and to its officials in the Chicago Region V Office who have provided the freedom for thought and experimentation in an extremely convivial atmosphere essential for the success of an international cooperative program of this magnitude.

2. DISCLAIMER

The study discussed in this document was carried out as part of the efforts of the Pollution from Land Use Activities Reference Group, an organization of the International Joint Commission, established under the Canada-U.S. Great Lakes Water Quality Agreement of 1972. Funding was provided through the U.S. Environmental Protection Agency. Findings and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

3. ACKNOWLEDGEMENT TO PROJECT PERSONNEL

The principal investigators of the Menomonee River Pilot Watershed Study are indebted to the following personnel for maintaining the essential flexibility of thought to accomplish the objectives of a program under continuous scrutiny and hence subject to improvement through changes initiated by Study personnel, the International Reference Group members and the personnel in all facets of the PLUARG program:

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7. SUMMARY

The Menomonee River watershed has been instrumented to allow main-stem and tributary monitoring at 15 locations. Furthermore, three of these and seven other study sites have been delineated which permit collection and analysis of drainage water from areas of predominantly one land use. An overland flow model (LANDRUN) has been developed, calibrated and verified for three subwatersheds in the Menomonee River basin. Detailed land use inventories (Southeastern Wisconsin Regional Planning Commission — SEWRPC) are available for 1970 and 1975 allowing a capability for examining the impact of changing land use patterns on pollutional loadings. A prediction of land use changes planned to the year 2000 will be used to expand the time frame for the interpretation of changing land use patterns as they affect Great Lakes pollution. The land use inventory allows mapping in 42 land-use categories but these have been consolidated into 13 categories for the PLUARG investigation.

The watershed has been segregated into 48 subwatersheds and land use and physical characteristics information is available for each subwatershed. The subwatersheds, average 800 ha (range 500 to 1,600 ha) in size, are being evaluated for pollutional hazard by the LANDRUN model allowing principal pollutional sources in the watershed to be delineated. In the Menomonee — as in most other urban areas in the Great Lakes basin — stream channel modifications have taken place to allow rapid transference of water to the lake to decrease flood hazards. Because of this, the importance of pollutant transmission, transformations and delivery ratios in the stream are perhaps not important in the Menomonee River watershed and other urban areas in the Great Lakes basin.

Data is presented on annual, seasonal and unit area loadings at the river mouth (70th St.) and at each of the mainstem monitoring stations and a stratified random sampling model enhanced by a ratio estimator is discussed for calculating loadings. For those areas predominantly in a single land use, unit area loadings are presented as is the relative distribution of point and diffuse sources of pollution at the river mouth. The principal parameters of concern in the Menomonee River watershed are suspended sediment, total phosphorus and lead since loadings of other toxic elements and organic materials are extremely low.

Simulation data on loadings at the river mouth arising from each of

the 13 land use categories has been determined and a hazard scale for land use has been developed. A discussion of the physical characteristics and of the composition and particle size distribution of soils and bottom and suspended sediments in the basin is presented. The importance of this information in the development of remedial management strategies is presented and an evaluation of particle size distribution and dispersibility of sediments is used to shed some light on pollutant availability in the river and lakes.

Quality of groundwater in the basin has been measured and pollutional inputs from atmospheric sources have been evaluated. Areal imagery has been utilized to determine ground cover in the basin and the transferability of this technique to other urban centers has been tested. Some attempts to establish a biological indicator of pollution have had only limited success.

The importance of the Menomonee River watershed data in meeting the goals of PLUARG are discussed and the extent to which Menomonee River watershed information and methodology is transferable to other sectors of the Great Lakes basin is realistically evaluated.

8. INTRODUCTION

Concern for the effects of various land use activities on Great Lakes water quality has prompted the governments of the United States and Canada, under the Great Lakes Water Quality Agreement of April 15, 1972, to direct the International Joint Commission to conduct studies of the impact of land use activities on the water quality of the Great Lakes Basin and to recommend remedial measures for maintaining or improving Great Lakes water quality.

To effect this undertaking, the International Joint Commission, through the Great Lakes Water Quality Board, established the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG). The Reference Group developed a study program which consisted of four major tasks. Task A is devoted to the collection and assessment of management and research information and in its later stages, to the critical analysis of implications of potential recommendations. Task B requires the preparation of a land use inventory, largely from existing data, and secondly, the analysis of trends in land use patterns and practices. Task C is the detailed survey of selected watersheds to determine the sources of pollutants, their relative significance and the assessment of the degree of transmission of pollutants to boundary waters. Task D is devoted to obtaining supplementary information on the impacts of materials to the boundary waters, their effect on water quality and their significance in these waters in the future and under alternative management schemes.

The Task C portion of the Detailed Study Plan includes intense investigations of watersheds in Canada and the United States which are representative of the full range of urban and rural land uses found in the Great Lakes Basin. A Task C Technical Committee and a Synthesis and Extrapolation Work Group have been established by PLUARG and assigned primary responsibility for developing and conducting the pilot watershed studies. The Menomonee River watershed was selected for the study of the effects of urban-residential land uses undergoing rapid change.

The Wisconsin Department of Natural Resources (WDNR), the University of Wisconsin System through the Water Resources Center (UW-WRC) and the Southeastern Wisconsin Regional Planning Commission (SEWRPC) serve as the

lead agencies or organizations responsible for conducting the intensive study of water quality-land use relations in the Menomonee River watershed.

The principal functions of these agencies are:

a. Wisconsin Department of Natural Resources: The WDNR is the lead agency and as such, administers the total study including coordination of activities associated with the Menomonee River Study and submission of reports to the U.S. Environmental Protection Agency and PLUARG. WDNR also provides laboratory support for the monitoring program to be conducted in the Menomonee River basin.

b. University of Wisconsin System: The UW-WRC has conducted special studies of selected land use activities and provided interpretation and assessment of monitoring data through development of land use-water quality models.

c. Southeastern Wisconsin Regional Planning Commission: The SEWRPC has provided background inventories on land use activities and projected land use patterns from its current Menomonee River planning program and developed a computer file of all data and information applicable to the study.

The 35,483 ha Menomonee River watershed is located in the southeastern corner of Wisconsin and discharges to Lake Michigan at the City of Milwaukee. This highly urbanized watershed encompasses all or parts of four counties and 17 cities, villages and towns and currently contains a resident population of about 400,000 persons (12 persons/ha). Existing urban land uses range from an intensely developed commercial-industrial complex in the lower quarter of the watershed to low to medium density residential areas in the center half of the watershed, while the upper quarter is in the process of being converted from rural to urban land use, as reflected by scattered urban development. The irregular topography of the watershed results from the effects of glaciation. Heterogeneous glacial drift covers the entire watershed and the dominant soil types tend to be poorly drained. The long-term average discharge from the watershed is 2.2 m^3/sec but flood flows as high as 500 m^3/sec have been recorded. The basin has a typical humid climate, with mild summers and cold winters. The annual average temperature is 10°C with mean daily temperatures ranging from -6°C in January to 21°C in July. Annual average precipitation is 79 cm (100 cm of snow).

Several key factors entered into selection of the Menomonee River watershed. Not only is the watershed highly urbanized, but the watershed and contiguous lands contain a full range of urban uses including low to high density residential areas, extensive commercial and industrial tracts and a considerable amount of land devoted to transportation facilities. The high degree of diversity of urban land uses in this watershed is reflected by the existence of combined and separate sewer systems. A dynamic dimension is added by the rapid development occurring in the upper quarter of the basin where agricultural land is being converted to urban land uses. A unique facet of the Menomonee watershed stems from the proposed plan to remove all municipal point sources of pollution by 1983, at which time the effects of land use on water quality will arise almost entirely from diffuse sources. Thus, of the major watersheds chosen for intensive study in the PLUARG program, the Menomonee watershed serves as the focus of investigations on the impact of urban land uses on water quality.

9. DATA COLLECTION METHODS

The data collection techniques used to investigate the pollutant contribution to surface and groundwater from land use activities rely on monitoring the amounts of certain constituents in surface water runoff, groundwater and the atmosphere (geohydrochemical cycle). Monitoring in some phases of the study were initiated in 1975 and all phases were operational by 1976.

The watershed has been instrumented to allow mainstem and tributary monitoring at 15 locations (12 of the stations are automated and three are grab sampling stations). Furthermore, three of these and seven other study sites have been delineated which permit collection and analysis of drainage water from areas predominantly in one land use. Seventy-five runoff events were monitored at the river stations and 57 at the specific study sites during 1976 and this effort is continuing through 1977. Base flow has been monitored to determine the relative significance of base flow to event loadings. Eight rainfall gauges in the watershed are positioned to allow correlation of rainfall intensities with measured pollutant loadings.

Dry and wet atmospheric fallout of material is being measured in the watershed. Rainfall is collected in Wong automatic samplers and analyzed for nutrients and toxic metals. Two cascade impactors are used to obtain particle size segregation of dry fallout which provides some limited information on sources of atmospheric pollutants.

Thirty-eight observational wells have been established in the watershed as part of the groundwater study. Monthly water samples are collected and analyzed for dissolved nutrients and metals. The groundwater flow system has been defined in the vicinity of the Menomonee River and an assessment of pollutant movement from the river to groundwater or from groundwater to the river has been made.

The data collected allows sources of pollutants in the watershed to be delineated using the LANDRUN overland flow model. The data also is used to calibrate models to assist in the assessment of the factors which principally influence pollutant loadings to Lake Michigan.

10. EXPERIMENTAL RESULTS

This section consists of data summaries that are generated from the Menomonee River Pilot Watershed Study. These data are generally available in each of the Watershed study groups to allow comparison of results to be made between watersheds. Data assessment is by no means complete at this time and information that is to be added in the final summary report is indicated in many of the tables. The data summaries are presented in logical order as follows: land use and land use practices; key parameters that are identified to be the main land-derived pollutants in the Great Lakes Basin, annual and seasonal loading data from the river mouth and predominant land use areas; physical characteristics of the watershed including soil type, slope and imperviousness; and particle size distribution and composition of soils and sediment in the watershed.

A. LAND USE

The characteristics of the land surface within a watershed are a major factor in determining the type, volume and timing of diffuse source pollution. The results of a 1970 and 1975 land use inventory for the Menomonee River watershed are summarized in the form of 13 aggregated land use categories in Table 1. Earlier discussions with principle investigators on Task C projects had indicated that a ten land use category would be adopted throughout the Great Lakes basin. However, additional categories were required within the Menomonee River watershed to more completely describe the land uses within the basin. Eleven of these aggregated land use categories for 1975 data are used in the LANDRUN model to develop a relative degree of hazard ranking for suspended solids, total phosphorus and lead loadings for the watershed as described in section 10C.

During 1975 approximately 49% of the land surface of the watershed was devoted to urban land use with the dominate land use being commercial. Within the rural land use, row crops are the dominant land use.

Urban and rural land use are not uniformly distributed over the watershed. Urban land uses are predominantly concentrated in the downstream or southern half of the watershed whereas rural land uses are found primarily in the upstream or northern half of the watershed.

The Menomonee River watershed has undergone a drastic change in land use over the last 20 years. From 1950 to 1970, a 42% increase in population was accompanied by a 156% increase in urban land use. It is expected that development will continue in the watershed but hopefully predicated on planning recommendations of the Southeastern Regional Planning Commission.

Other land factors such as, soil type, slope, imperviousness and the type and degree of land management also affect the diffuse source pollution loads. These physical characteristics of the watershed are presented in Section 10D.

Fig. 1 and Table 2 show the location and associated land uses for the monitoring stations within the watershed. This table allows a rapid evaluation of the distribution of the different land uses at each monitoring station. It should be noted that the first three stations have been aggregated under one land use breakout since the land uses were not determined for each of the stations. Summation of the individual land use

Table 1. Urban and rural land use inventories for the Menomonee River watershed in 1970 and 1975 as determined by the S. E. Wisconsin Regional Planning Commission

Land use category*		Type of land use	Area, ha		Distribution, %	
			1970	1975	1970	1975
		URBAN LAND USES				
1.	Industrial	Manufacturing and extractive	588	612	1.68	1.74
2.	Commercial	Retail, wholesale, service, transportation, communication and utilities**	6,612	6,542	18.8	18.5
3.	High-density residential	Multi-family and mobile homes	332	429	0.94	1.22
4.	Medium-density residential	Two-family and 50% of single family dwellings	4,035	4,493	11.5	12.7
5.	Low-density residential	50% of single family dwellings and all farm buildings except feedlots	3,556	4,174	10.1	11.8
6.	Land under development	Residential	824	711	2.34	2.02
		All other types	199***	205	0.57	0.58
	SUB TOTAL - Urban		16,146	17,166	46.0	48.6
		RURAL LAND USES				
7.	Row crops	Row crops and vegetables	5,491	4,809	15.6	13.6
8.	Pastures and small grains	Grain crops, hay pasture, park and recreational land, governmental and institutional** and unused land	10,533	9,945	30.0	28.2
9.	Forested lands and woodlots	Woodlands, orchards and nurseries	1,677	1,970	4.77	5.58
10.	Wetlands	Swamps, marshes and wetlands	997	1,070	2.84	3.03
11.	Feedlots	Feedlots	39	32	0.11	0.09
12.	Landfills and dumps	Landfills and dumps	101	120	0.29	0.34
13.	Water areas	Lakes, rivers, streams and canals	145	185	0.41	0.53
	SUB TOTAL - Rural		18,983	18,131	54.0	51.4
	TOTAL - Watershed+		35,129	35,297	100	100

*Land use definitions will be compared with PLUARG definitions when available.

**In the Menomonee watershed most governmental and institutional buildings are associated with large, open parklands and are included in Category 8. In other watersheds where these buildings are associated with a commercial district, they are better included in Category 2.

***Estimated by taking ratio of residential to other types of land under development in 1975.

+The 1975 data are more accurate because hectare-sized cells were summed; 1970 data were based on 0.25 mi^2 cells.

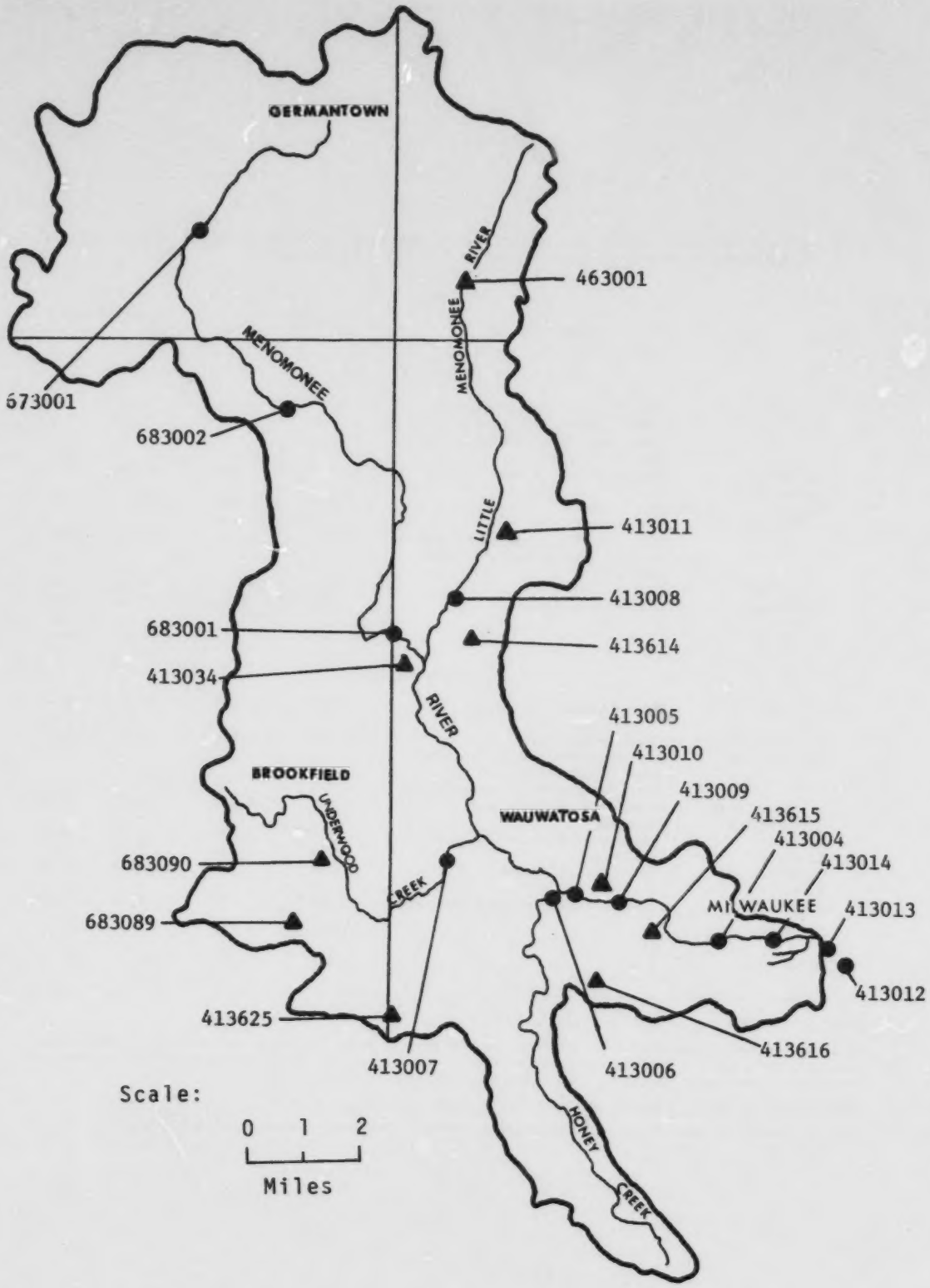

Fig. 1. Station locations within the Menomonee River watershed. ● indicates stations monitoring drainage areas of multi-land uses and ▲ indicates stations monitoring drainage areas of predominate land uses.

Table 2. Menomonee River watershed monitoring stations* with areas for each land use category in 1975

STORET Number	Location	Land use category,** ha													
		1	2	3	4	5	6	7	8	9	10	11	12	13	Total
413012	Harbor at Hwy. 32 bridge)														
413013	Menomonee River (M.R.) at 2nd St bridge)	60	509	41	102	42	7	0	85	0	0	0	0	28	874
413014	M.R. at N. 13th St bridge)														
413004	M.R. above 27th St at Falk Corporaton	133	800	30	346	193	4	0	293	0	0	0	14	15	1,828
413009	M.R. at Hawley Rd	0.04	63	3	64	31	0.22	0	21	0	0	0	0	0	182
413005	M.R. at 70th St bridge	105	1,340	94	595	522	27	11	1,000	7	0	0	2	34	3,737
413006	Honey Creek 140 m above confluence with M.R.	24	778	91	673	590	49	15	524	14	9	0	13	4	2,784
413007	Underwood Creek above Hwy 45 off North Ave	76	1,013	53	991	984	145	29	1,307	184	138	0	40	12	4,972
683001	M.R. at 124th St (Hwy.M)	106	848	11	858	887	302	938	2,194	294	164	3	22	31	6,658
413008	Little M.R. at Appleton Ave (Hwy. 175)	26	343	46	167	168	114	389	909	182	99	0.4	13	7	2,463
683002	M.R. at Pilgrim Rd (Hwy. YY)	27	342	12	327	355	130	864	1,281	336	331	3	1	16	4,025
673001	M.R. at River Lane Rd (Hwy. F)	10	278	25	128	171	56	1,621	1,593	515	281	14	0	22	4,714
463001	Donges Bay Rd, Mequon	0	56	1	83	100	34	938	648	210	49	12	0	14	2,145
413010	Schoonmaker Creek at Vliet St	0	48	1	70	48	3	0	9	0	0	0	0	0	179
413011	Noyes Creek at 91st St	10	193	21	88	81	15	0	127	2	0	0	15	2	554
413625	City of W. Allis at 124th St and Greenfield Ave	0	31	2	0	127	6	0	56	2	0	0	0	0	224
683090	Village of Elm Grove, ditch at Underwood Pkwy	0	20	0	0	131	6	0	5	4	0	0	0	0	166
413614	Timmerman Airport, manhole #6	0	140	0	0	1	0	0	0	0	0	0	0	0	141
413615	Stadium interchange I-94, manhole #120	0	35	0	11	0	0.1	0	18	0	0	0	0	0	64
683089	Brookfield Shopping Center	0	40	0	5	0	0	0	16	0	0	0	0	0	61
413034	City of Wauwatosa, off Ferrick St	25	63	0	8	0	0	0	14	0	0	0	0	0	110
413616	Allis-Chalmers Corp., W. Allis	38	11	0	0	0	0	0	0	0	0	0	0	0	49

*All stations are automatic sampling and continuous flow monitoring except station number 413004 which is automatic sampling only; station number 413009, a stormwater monitoring station which has automatic sampling and continuous flow, depending on flow conditions; and the harbor stations, numbers 413012, 413013 and 413014 are grab sampling stations.

**Land use categories are defined in Table 1.

totals for the first 15 stations will approximately equal the total area of the watershed. The remaining stations are contained within the drainage areas of the first group. The drainage areas of the 15 mainstem stations range in size from a maximum of 6,658 ha to a minimum of 179 ha with an average of approximately 3,200 ha, allowing an initial segmentation of the basin into 13 subbasins.

B. KEY PARAMETERS

Following a series of meetings with participants of the pilot watershed projects and personnel of the EPA laboratory in Duluth, Minnesota, SEWG identified two major types of pollution arising from nonpoint sources in the Great Lakes Basin, namely, nutrients and sediment which accelerate eutrophication of the lakes and toxic materials which constitute a public health hazard and a hazard to the biological communities of the lakes. The basic guidelines used in selecting key parameters for these types of pollution are (1) the pollutant must be present in significant amounts in the watershed and (2) it must be amenable to remedial control measures. The key parameters selected include suspended sediment; total phosphorus; toxic metals primarily Pb, Cd, Cu, and Zn; and toxic organic materials principally pesticides, PCB, and phenols. In the Menomonee River watershed study, other metals (Fe, Mn, Al, Ni, Cr, As, and Se) have been monitored, however, some of them are present in low concentrations while others do not pose any health hazard. Pesticides, PCB, and phenols have been measured but then concentrations are generally below detection limits making quantification of loadings difficult. Pesticides may be a local problem and the impact of their usage on the water quality of the Great Lakes can be evaluated from the data obtained from the Mill Creek pesticide study in Michigan.

Thus, the parameters deemed to be of greatest importance in the Menomonee River watershed are: suspended sediment, total phosphorus and lead.

C. LOADING DATA

The assessment of the magnitude of pollution from land use activites is based on the determination and evaluation of the loadings of key parameters from the various monitoring stations within the watershed. Available loading calculation methods are briefly evaluated and the process for applying a stratified random sampling method is discussed.

Annual and seasonal total and unit loadings were calculated using a stratified random sampling model enhanced by a ratio estimator. Annual and seasonal total loadings values for the river mouth station and annual and seasonal unit loading values for the multiple and predominant single land use subwatersheds are summarized in tabular form. Point source contribution from the four treatment facilities, the only major points sources within the watershed were determined and the loads were subtracted from the appropriate diffuse source loading data to determine the true diffuse source loading.

The loading values will be used, concomitantly with the LANDRUN model, to develop a relative hazard ranking scale for 11 land use categories within the Menomonee River watershed.

i. Loading calculation

The term "hazardous land use" is relative, being defined as a land use from which significantly greater amounts of a pollutant are derived. It is possible to calculate pollutant loads from land use activities in a number of ways, however, it must be kept in mind that the estimates should be unbiased, that is, on the average correct and capable of being statistically compared, summed and assessed. Consequently, the method of calculating loads should a) be consistent with the assumptions associated with the sampling schemes that were used, and b) enable an estimate of the variance associated with each load to be determined (to permit a statistical comparison).

Initially, loads for the Menomonee River watershed were calculated using an "integration" method whereby loading values were possible only for events for which concentration data were available. This "model" linearly interpolated between measured concentration data points in order to assign a concentration for each measured instantaneous flow. For events during which extensive concentration information is available, this interpolation routine can be a reasonable approximation of concentration variation over time. For events with limited concentration information, the interpolation routine can introduce unsystematic (and unquantifiable) variation. For events with flow records for which there is no concentration information, the integration method is not usable.

John Clark, IJC statistician, proposed (March, 1977, PLUARG Task C Handbook Amendments) that a stratified random sampling model enhanced by a ratio estimator be used for load calculations. The assumptions of the model proposed by Clark are: a) simple random sampling of water quality withing nonoverlapping subpopulations or strata, and b) use of available supplemental population flow information for the several strata (rather than instantaneous flows only for those times when water quality samples were taken). This model was used in a manner consistent with the sampling schemes to produce unbiased loading values with standard error terms and the degrees of freedom associated with these estimates. In addition, the 95% confidence interval for each load was calculated (using the form $\bar{x} \pm t\, s(\bar{x})$, where $\bar{x}$ is the estimated loading value, $s(\bar{x})$ is the standard error, and t is the value from the student's t table for the calculated degree of freedom for a 95% confidence interval).

The statistical technique of stratifying subsample data was applied in the calculation of loads in order to provide more precision in the loading estimate for a particular parameter by clustering units which are homogeneous in terms of concentration of that parameter. The underlying assumption is that the population of all water quality concentrations of the parameter of interest can be more accurately represented as the sum of subpopulations, rather than as a single, homogeneous population. The determination of strata was critical, since these strata reflected the hypothesized (or observed) subpopulations of water quality concentrations.

Using a stratification scheme which included: (1) season, (2) event versus nonevent within each season, and (3) high flow versus low flow times within the events, loading estimates were calculated for the sampling stations.

ii. Monitored annual, seasonal and unit area loading data

Annual and seasonal river mouth loadings of suspended sediment, total phosphorus and lead determined at the 70th St. Station (413005), in 1975, 1976 and part of 1977 are presented in Table 3. The spring season was determined by the period of high flows resulting from snowmelt and was March 14 to June 1 in 1975, February 2 to June 1 in 1976 and March 3 to June 1 in 1977; other dates defining summer, fall and winter were determined by solar demarcation. River mouth loadings of suspended sediment and total phosphorus were invariably higher in spring and summer than in fall and winter. Seasonal loadings varied considerably between the years, nonetheless annual loadings of suspended sediment and total phosphorus were similar for 1975 and 1976. Seasonal variability in loadings could be accounted for by differences in rainfall distribution. The largest portion of the annual loadings of suspended sediment and total phosphorus was generated during events. This leads to the conclusion that the point source contribution of suspended sediment was insignificant and of total phosphorus was small.

Loading values at the river mouth will be used to determine delivery ratios for the watershed. In this context, delivery ratio is the ratio of the amount of material arriving at the river mouth compared with the amount of material generated at the source. The primary significance of the river mouth loadings is to allow an assessment of their in-lake effects.

The river mouth loadings represent an integration of all pollutants for the total range of land use activities in the basin. As such, these data are of no value in defining those areas, land uses or land-use practices which are of particular hazard to Lake Michigan. The seasonal unit area loadings at each of the main stem river stations (Tables 4, 5, 6 and 7) and at those stations draining an area of predominantly one land use (Tables 8, 9 and 10) allowed an initial segregation of the watershed into 13 subwatersheds of average area of 2,700 ha.

Relatively high annual loadings of suspended sediment were found at stations 413006 and 413008 in 1975, 1976 and 1977. Similarly, total phosphorus loadings were high at stations 413005, 413006 and 683001 in 1976 and at stations 413005, 413006 and 413009 in 1977. Station 683007 is a main

Table 3. Event and total* loadings at the mouth (70th St) of the Menomonee River (413005)

Loading category	Winter		Spring		Summer		Fall		Annual	
	Sus. solids	Total phos.	Sus. solids	Total phos.	Sus. solids	Total phos.	Sus. solids	Total phos.	Sus. solids	Total phos.
					1975					
Total, kg	1,260,000 (209,200)**	4,740 (2,910)	4,362,000 (954,100)	17,160 (4,934)	5,281,000 (1,037,000)	10,600 (2,095)	623,600 (143,300)	3,524 (1,808)	11,527,000 (1,415,000)	36,030 (5,394)
Event, kg	1,011,000 (182,900)	i.d.	4,095,035 (953,700)	i.d.	4,543,000 (579,900)	i.d.	460,700 (132,100)	i.d.	10,111,000 (1,143,000)	i.d.
Event, kg/ha	31.4 (5.7)	i.d.	127.1 (29.6)	i.d.	191.0 (18.0)	i.d.	14.3 (4.1)	i.d.	313.8 (35.5)	i.d.
					1976					
Total, kg	17,520 (4,195)	543 (88)	7,964,000 (828,600)	22,250 (2,003)	1,392,000 (353,400)	3,772 (547)	183,000 (60,990)	1,734 (380)	9,556,000 (899,900)	28,300 (2,100)
Event, kg	i.d.	i.d.	7,423,000 (828,000)	14,788 (1,997)	1,160,000 (338,300)	2,094 (451)	135,300 (54,770)	548 (161)	8,722,000 (892,500)	17,430 (2,062)
Event, kg/ha	i.d.	i.d.	230.4 (25.7)	.459 (.062)	36.0 (10.5)	.065 (.014)	4.2 (1.7)	.017 (.005)	270.7 (27.7)	.541 (.064)
					1977					
Total, kg	i.d.	i.d.	1,419,000 (265,900)	4,141 (552)	5,896,000 (938,100)	9,916 (1,405)	i.d.	i.d.	i.d.	i.d.
Event, kg	i.d.	i.d.	1,308,000 (264,200)	1,772 (419)	5,419,000 (924,700)	6,798 (1,353)	i.d.	i.d.	i.d.	i.d.
Event, kg/ha	i.d.	i.d.	40.6 (8.2)	.055 (.013)	168.2 (28.7)	.211 (.042)	i.d.	i.d.	i.d.	i.d.

*Total represents baseflow and event loads

**Value in parentheses is the 95% confidence interval

i.d. Data insufficient for the determination of a seasonal load.

Table 4. Event unit loadings of suspended solids at main stem river stations

STORET number	Loadings, kg/ha			
	Spring	Summer	Fall	Total
		1975		
673001	36.7 (4.5)*	3.6 (0.8)	2.0 (5.7)	42.3 (6.1)
683002	43.2 (7.5)	44.1 (19.2)	6.8 (1.7)	94.1 (20.8)
683001	34.2 (21.4)	71.5 (12.8)	4.3 (1.2)	110 (24.7)
413008	238 (61.7)	212 (50.3)	46.4 (22.5)	497 (81.0)
413007	286 (74.6)	178 (55.7)	2.8 (9.1)	466 (92.8)
413006	288 (72.1)	147 (24.4)	45.9 (14.7)	480 (77.3)
413005	127 (29.6)	141 (18.0)	14.3 (4.1)	282 (35.0)
413009	i.d.	i.d.	i.d.	i.d.
413004	i.d.	13.3 (9.3)	i.d.	i.d.
		1976		
673001	12.7 (3.8)	0.2 (0.1)	0.06 (0.02)	13.0 (3.8)
683002	36.6 (11.4)	1.6 (1.0)	0.1 (0.1)	38.3 (11.5)
683001	136 (36.8)	6.0 (2.7)	0.4 (0.1)	143 (36.9)
413008	467 (131)	58.1 (47.6)	1.4 (0.5)	527 (136)
413007	133 (42.7)	37.9 (27.2)	7.4 (6.1)	178 (49.5)
413006	835 (149)	76.7 (15.1)	10.0 (1.9)	922 (150)
413005	230 (25.7)	36.0 (10.5)	4.2 (1.7)	271 (27.7)
413009	130 (35.4)	30.3 (7.8)	i.d.	160 (36.3)
413004	266 (65.8)	10.0 (9.0)	i.d.	276 (66.4)
		1977		
673001	1.6 (0.6)	13.5 (9.0)	i.d.	15.1 (9.0)
683002	7.5 (4.6)	39.1 (9.9)	i.d.	46.6 (10.7)
683001	44.5 (15.0)	80.6 (17.2)	i.d.	125 (22.5)
413008	95.1 (26.2)	180 (35.2)	i.d.	275 (43.4)
413007	26.2 (11.2)	84 (37.8)	i.d.	110 (39.8)
413006	129 (29.7)	452 (62.7)	i.d.	581 (68.7)
413005	40.6 (8.2)	168 (28.7)	i.d.	209 (29.8)
413009	34.4 (6.6)	87.6 (49.8)	i.d.	122 (49.8)
413004	36.4 (28.5)	97.0 (26.9)	i.d.	133 (36.9)

* () 95% confidence interval

i.d. Data insufficient for the determination of a seasonal load

Table 5. Event unit loadings of total P at main stem river stations

STORET number	Loadings, kg/ha			
	Spring	Summer	Fall	Total
		1975		
673001	i.d.	i.d.	i.d.	i.d.
683002	i.d.	i.d.	i.d.	i.d.
683001	i.d.	i.d.	i.d.	i.d.
413008	i.d.	i.d.	i.d.	i.d.
413007	i.d.	i.d.	i.d.	i.d.
413006	i.d.	i.d.	i.d.	i.d.
413005	i.d.	i.d.	i.d.	i.d.
413009	i.d.	i.d.	i.d.	i.d.
413004	i.d.	i.d.	i.d.	i.d.
		1976		
673001	0.072 (0.012)*	0.004 (0.000)	0.002 (0.000)	0.077 (0.013)
683002	0.066 (0.043)	0.004 (0.000)	0.000 (0.000)	0.070 (0.043)
683001	0.50 (0.11)	0.030 (0.022)	0.003 (0.000)	0.54 (0.11)
413008	0.46 (0.15)	0.001 (0.000)	0.001 (0.000)	0.46 (0.15)
413007	0.31 (0.16)	0.006 (0.000)	0.004 (0.000)	0.32 (0.16)
413006	0.64 (0.48)	0.19 (0.12)	0.048 (0.009)	0.88 (0.48)
413005	0.46 (0.062)	0.065 (0.014)	0.017 (0.005)	0.54 (0.064)
413009	i.d.	0.16 (0.078)	i.d.	i.d.
413004	0.24 (0.063)	0.018 (0.000)	0.017 (0.002)	0.27 (0.063)
		1977		
673001	0.004 (0.004)	0.10 (0.043)	i.d.	0.11 (0.043)
683002	0.016 (0.007)	0.061 (0.011)	i.d.	0.077 (0.012)
683001	0.085 (0.024)	0.16 (0.028)	i.d.	0.24 (0.036)
413008	0.068 (0.022)	0.13 (0.042)	i.d.	0.20 (0.046)
413007	0.040 (0.025)	0.11 (0.054)	i.d.	0.15 (0.050)
413006	0.28 (0.17)	0.49 (0.11)	i.d.	0.77 (0.20)
413005	0.055 (0.013)	0.21 (0.042)	i.d.	0.26 (0.044)
413009	0.24 (0.047)	0.54 (0.45)	i.d.	0.77 (0.45)
413004	0.050 (0.029)	0.19 (0.079)	i.d.	0.24 (0.083)

* () 95% confidence interval

i.d. Data insufficient for the determination of a seasonal load

Table 6. Average of seasonal event unit loadings for suspended solids at main stem river stations from 1975 to 1977

STORET number	Spring		Summer		Fall		Total	
	Loading, kg/ha	No. of years	Loading, kg/ha	No. of years	Loading, kg/ha	No. of years	Loading, kg/ha	No. of years
413011	842 (137)*	3	390 (163)	3	70.0 (50.0)	2	1,302 (214)	3
413006	417 (56.0)	3	225 (23.0)	3	28.0 (7.0)	2	670 (61.0)	3
413008	267 (49.0)	3	150 (24.0)	3	24.0 (11.0)	2	441 (55.0)	3
463001	304 (44.0)	2	39 (12.0)	3	1.0 (0.3)	1	344 (45.0)	3
413010	157 (29.0)	3	147 (44.0)	3	33.0 (25.0)	2	337 (53.0)	3
413005	133 (13.0)	3	115 (12.0)	3	9.0 (2.0)	2	257 (18.0)	3
413007	148 (29.0)	3	100 (24.0)	3	5.0 (3.0)	2	253 (37.0)	3
413004	151 (35.0)	2	54 (14.0)	2	13.0 (9.0)	1	218 (38.0)	3
413009	82 (18.0)	2	59 (25.0)	2	i.d.	0	141 (30.0)	2
683001	72 (15.0)	3	53 (7.0)	3	2.0 (0.6)	2	127 (17.)	3
673002	29 (5.0)	3	28 (7.0)	3	3.0 (0.9)	2	60 (9.0)	3
673001	17 (2.0)	3	6 (3.0)	3	1.0 (3.0)	2	24 (4.0)	3

* () 95% confidence interval
i.d. Insufficient data

Table 7. Average of seasonal event unit loadings for total P at main stem river stations from 1975 to 1977

STORET number	Spring		Summer		Fall		Total	
	Loading, kg/ha	No. of years	Loading, kg/ha	No. of years	Loading, kg/ha	No. of years	Loading, kg/ha	No. of years
413011	0.61 (0.19)*	2	0.36 (0.22)	2	0.01 (0.01)	1	0.98 (0.29)	3
413006	0.46 (0.25)	2	0.34 (0.08)	2	0.05 (0.01)	1	0.85 (0.25)	3
463001	0.61 (0.17)	1	0.07 (0.03)	2	i.d.	0	0.68 (0.17)	2
413009	0.24 (0.05)	1	0.35 (0.23)	2	i.d.	0	0.59 (0.23)	2
413010	0.27 (0.19)	2	0.24 (0.10)	2	0.02 (0.02)	1	0.53 (0.20)	3
413005	0.26 (0.03)	2	0.14 (0.02)	2	0.02 (0.01)	1	0.41 (0.04)	3
683001	0.29 (0.06)	2	0.10 (0.02)	2	0.01 (0.00)	1	0.39 (0.06)	3
413008	0.26 (0.07)	2	0.07 (0.02)	2	<0.01 (0.00)	1	0.33 (0.08)	3
413004	0.14 (0.03)	2	0.10 (0.04)	2	0.02 (0.00)	1	0.26 (0.05)	3
413007	0.17 (0.08)	2	0.06 (0.03)	2	0.01 (0.00)	1	0.24 (0.08)	3
673001	0.04 (0.01)	2	0.05 (0.02)	2	<0.01 (0.00)	1	0.09 (0.02)	3
683002	0.04 (0.02)	2	0.03 (0.01)	2	<0.01 (0.00)	1	0.07 (0.02)	3

*() 95% confidence interval
i.d. Insufficient data

Table 8. Event unit loadings* of suspended solids, water and average concentration** at the predominant land use stations

STORET number	Spring			Summer			Fall			Winter			Total		
	Water loading m^3/ha	S.S. loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	S.S. loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	S.S. loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	S.S. loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	S.S. loading kg/ha	Ave. conc. mg/l
							1975								
463001	620	202 (58)+	325	85	31 (8)	364	22	1.0 (0.3)	45		i.d.		727	234 (58)	322
413011	319	260 (54)	815	538	261 (48)	485	383	136 (100)	355		i.d.		1240	657 (116)	530
413010	553	144 (56)	260	460	87 (17)	161	64	62 (123)	968		i.d.		1077	293 (61)	272
							1976								
463001	1290	406 (68)	314	17	3.6 (7)	212	0	0 (0)			i.d.		1307	410 (68)	313
413011	2927	2193 (406)	749	223	41 (8.5)	183	76	3.3 (1.1)	43		i.d.		3226	2237 (405)	693
413010	608	198 (28)	325	143	75 (47)	524	45	4.6 (82)	102		i.d.		796	277 (56)	348
413625		++		1	0.26 (0.24)	236	3	0.04 (0.03)	13		i.d.		4	0.31 (0.24)	84
683090		i.d.		0	0 (0)	0	0	0 (0)	0	0	0 (0)	0	0	0 (0)	0
413614		i.d.		139	63 (9.3)	454	18	1.2 (0.24)	65	25	1.0 (0.23)	40	182	65 (8)	358
413615		++		127	10 (7.9)	78	14	4.2 (6.8)	306	92	36 (16)	391	234	50 (17)	216
683089		i.d.		358	78 (53)	218	90	6.0 (4.5)	66		i.d.		448	84 (13)	188
413616		++		758	202 (78)	266	29	4.0 (3.8)	136		i.d.		788	206 (78)	261
							1977								
463001		i.d.		85	83 (34)	976									
413011	247	72 (27)	291	986	867 (487)	879									
413010	227	130 (67)	572	648	280 (123)	432									
413625	97	6.6 (2)	67	32	12 (5.9)	376	9	1.0 (0.27)	103	0	0 (0)	0	138	19.6 (5.9)	142
683090	39	0.94 (0.22)	24	38	1.1 (0.68)	28	30	1.0 (0.07)	35	0	0 (0)	0	106	3.04 (0.7)	28
413614	142	16 (11)	112	457	72 (28)	157	240	7.1 (4.5)	30	0	0 (0)	0	839	95 (29)	113
413615	443	230 (75)	519	1593	697 (275)	437	237	51 (26)	215	100	13.7 (4.9)	137	2373	992 (284)	418
683089	684	350 (349)	512	1247	195 (86)	156	103	3.6 (1.2)	35	0	0 (0)	0	2034	549 (357)	270
413616	508	79 (30)	155	3280	1625 (595)	495	230	2.8 (2.6)	12	0	0 (0)	0	4018	1707 (596)	425
413034	22	11 (10)	509	241	47 (25)	195	68	27 (5.5)	396	0	0 (0)	0	331	85 (26)	257

* Blanks indicate data to be calculated.
** Average concentration is the suspended solids load divided by the water load.
\+ ( ) 95% confidence interval.
++ Not operational.
i.d. Data insufficient for the determination of a seasonal load.

Table 9. Event unit loadings* of total phosphorus, water and average concentration** at the predominant land use stations

STORET number	Spring			Summer			Fall			Winter			Total		
	Water loading m^3/ha	T.P. loadings kg/ha	Ave. conc. mg/l	Water loading m^3/ha	T.P. loadings kg/ha	Ave. conc. mg/l	Water loading m^3/ha	T.P. loadings kg/ha	Ave. conc. mg/l	Water loading m^3/ha	T.P. loadings kg/ha	Ave. conc. mg/l	Water loading m^3/ha	T.P. loadings kg/ha	Ave. conc. mg/l
							1976								
463001	1290	0.61 (0.17)+	0.47	17	0.01 (0.01)	0.59	0	0 (0)			i.d.		1307	0.62 (0.17)	0.47
413011	2927	1.16 (0.39)	0.40	223	0.07 (0.02)	0.31	76	0.01 (0.01)	0.13		i.d.		3226	1.24 (0.39)	0.38
413010	608	0.29 (0.09)	0.48	143	0.12 (0.17)	0.84	45	0.02 (0.02)	0.44		i.d.		796	0.43 (0.19)	0.54
413625		++		1	0 (0)	0.57	3	0 (0)	0.29		i.d.		4	0 (0)	0.38
683090		i.d.		0	0 (0)	0	0	0 (0)	0	0	0 (0)	0	0	0 (0)	0
413614		i.d.		139	0.10 (0.02)	0.72	18	0.01 (0.002)	0.55	25	0.01 (0.003)	0.40	182	0.12 (0.03)	0.66
413615		++		127	0.02 (0.01)	0.15	14	0.01 (0.06)	0.72	92	0.08 (0.01)	0.86	233	0.11 (0.02)	0.47
683089		i.d.		358	0.10 (0.04)	0.28	90	0.02 (0.02)	0.22		i.d.		448	0.12 (0.04)	0.27
413616		++		758	1.02 (0.21)	1.34	29	0.03 (0.01)	1.02		i.d.		788	1.06 (0.21)	1.34
							1977								
463001	0	i.d.		85	0.13 (0.06)	1.52									
413011	247	0.06 (0.02)	0.24	867	0.65 (0.45)	0.75									
413010	227	0.24 (0.17)	1.05	280	0.36 (0.10)	1.28									
413625	97	0.04 (0.04)	0.41	12	0.01 (0.003)	0.31	9	0.002(0.001)	0.21	0	0 (0)	0	138	0.05 (0.04)	0.38
683090	19	0.01 (0.001)	0.25	18	0.02 (0.001)	0.92	10	0.01 (0.008)	0.14	0	0 (0)	0	106	0.04 (0.01)	0.37
413614	142	0.03 (0.02)	0.21	457	0.08 (0.03)	0.18	240	0.05 (0.03)	0.21	0	0 (0)	0	839	0.16 (0.03)	0.19
413615	443	0.24 (0.07)	0.54	1591	0.62 (0.17)	0.38	237	0.06 (0.04)	0.25	100	0.02 (0.01)	0.20	2373	0.94 (0.19)	0.39
683089	684	0.26 (0.22)	0.38	1247	0.22 (0.18)	0.18	101	0.01 (0.006)	0.09	0	0 (0)	0	2034	0.49 (0.27)	0.24
413616	508	0.45 (0.08)	0.88	1280	1.70 (0.86)	1.12	230	0.13 (0.003)	0.57	0	0 (0)	0	4018	4.28 (0.87)	1.06
413034	22	0.02 (0.02)	0.92	241	0.04 (0.01)	0.16	68	0.07 (0.01)	1.06	0	0 (0)	0	331	0.13 (0.18)	0.39

* Blanks indicate data to be calculated.
** Average concentration is the total phosphorus load divided by the water load.
\+ ( ) 95% confidence interval.
++ Not operational.
i.d. Data insufficient for the determination of a seasonal load.

Table 10. Event unit loadings* of lead, water and average concentration** at the predominant land use stations

STORET number	Spring			Summer			Fall			Winter			Total		
	Water loading m^3/ha	Pb loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	Pb loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	Pb loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	Pb loading kg/ha	Ave. conc. mg/l	Water loading m^3/ha	Pb loading kg/ha	Ave. conc. mg/l
							1976								
463001	1290	0.006(0.006)+	0.005		i.d.			i.d.			i.d.		*	i.d.	
413011	2927	0.18 (0.16)	0.06		i.d.			i.d.			i.d.			i.d.	
413010	608	0.06 (0.02)	0.10		i.d.			i.d.			i.d.			i.d.	
413625		++		1	0 (0)	0.23	3	0 (0)	0.01		i.d.		4	0 (0)	0.10
683090		i.d.		0	0 (0)	0	0	0 (0)	0	0	0 (0)		0	0 (0)	0
413614		i.d.		139	0.08 (0.05)	0.58	18	0.004(0.001)	0.22	25	0.004(0.002)	0.16	182	0.09 (0.03)	0.49
413615		++		127	0.04 (0.02)	0.31	14	0.03 (0.04)	2.18	92	0.26 (0.09)	2.82	233	0.33 (0.02)	1.42
683089		i.d.		358	0.19 (0.07)	0.53	90	0.04 (0.04)	0.44		i.d.		448	0.23 (0.08)	0.51
413616		++		758	1.42 (0.98)	1.87	29	0.02 (0.02)	0.68		i.d.		788	1.44 (0.98)	1.83
							1977								
463001		i.d.		85	0.008(0.005)	0.09									
413011	247	0.005(0.002)	0.02	986	0.15 (0.04)	0.15									
413010	227	0.25 (0.19)	1.10	648	0.28 (0.09)	0.43									
413625	97	0.007(0.002)	0.07	32	0.006(0.003)	0.19	9	0.001(0.001)	0.01	0	0 (0)	0	138	0.014(0.008)	0.10
683090	39	0.002(0.003)	0.05	38	0.003(0.001)	0.07	30	0.002(0.001)	0.07	0	0 (0)	0	106	0.007(0.002)	0.06
413614	142	0.03 (0.01)	0.21	457	0.09 (0.05)	0.19	240	0.04 (0.01)	0.17	0	0 (0)	0	839	0.16 (0.05)	0.19
413615	443	1.09 (0.32)	2.46	1593	3.67 (2.02)	2.30	237	0.34 (0.24)	1.43	100	0.08 (0.06)	0.78	2373	5.18 (2.06)	2.18
683089	684	0.72 (0.59)	1.05	1247	0.44 (0.16)	0.35	103	0.011(0.008)	0.11	0	0 (0)	0	2034	1.17 (0.60)	0.57
413616	508	0.30 (0.12)	0.59	3280	6.65 (2.94)	2.02	230	0.04 (0.01)	0.17	0	0 (0)	0	4018	7.0 (0.87)	1.74
413034	27	0.02 (0.06)	0.92	241	0.07 (0.02)	0.29	68	0.11 (0.04)	1.60	0	0 (0)	0	331	0.20 (0.04)	0.60

* Blanks indicate data to be calculated.
** Average concentration is the lead load divided by the water load.
\+ ( ) 95% confidence interval.
++ Not operational.
i.d. Data insufficient for the determination of a seasonal load.

stem station situated just below two sewage treatment facilities. The point source contributions of total phosphorus to the upper watershed main stem stations, namely, 673001, 683002 and 683001 were particularly significant in 1975 (Table 11). Table 12 gives a comparison of the point source loads to the nonpoint loads for suspended solids, total phosphorus and water at the river mouth (70th St. station). The contribution of suspended solids and water is insignificant, however, about one-third of the total phosphorus load is from the treatment plants. Although data is not presently available, it is probable that the majority of the phosphorus is in the soluble form, given operating conditions at the plants. Since the majority of the effluent is discharged during non-event times (when the river is low in suspended solids), the plants represent a significant source of available phosphorus. Care should be exercised in evaluating this data, since plant position in the watershed is important in the evaluation of the loads between these point sources and the nonpoint sources.

By examination of the loadings and land use activities in the 13 sub-basins, those areas of particular hazard will be enumerated. The relative contribution from the various land use types will be further evaluated by sub-dividing the basin into 48 areas which will be assessed for pollutant loadings utilizing the simulation model — LANDRUN. The model will also be used to determine the effect of such factors as precipitation, topography, degree of imperviousness, etc., on observed pollutant loading values.

Seasonal runoff event pollutant loads (kg/ha), water loads (m^3/ha) and average concentrations (mg/l) for suspended solids, total phosphorus and lead were determined for the 10 predominant land use sites (Tables 8, 9 and 10; see Fig. 1 and Table 2 for location and land use description). Water loads and pollutant concentrations (and hence pollutant loads) varied considerably from season to season at each station and from station to station for each season. In the analysis of pollutant loadings, consideration must be given to their respective components. To the degree that concentrations are similar, variations in pollutant loadings are attributable to differences in the amount of runoff. Likewise, to the degree that the amounts of runoff are similar, variations in the pollutant loadings are due to differences in concentrations.

This dualistic analysis of stormwater pollution yields a two sided relative hazard-ranking system. On the one hand are the hydraulic factors

Table 11. Point source* loadings to the Menomonee River, kg

Parameter	Annual loadings for sewage treatment plants					Percent of annual total loads contributed by point sources at			
	Germantown	Riverside, Menomonee Falls	Parkside, Menomonee Falls	Butler Bypass	Total annual	673001	683002	683001	413005
				1975					
S.S.	13,800	44,400	22,000	10,300	90,500	3	1	3	1
T.P.	2,900	7,900	1,900	1,200	13,800	91	46	76	40
Flow, m^3	1,249,000	1,930,000	1,098,000	397,000	4,674,000	10	5	10	5
				1976					
S.S.	18,700	37,800	13,600	7,900	78,000	6	3	3	1
T.P.	900	4,000	1,600	900	7,400	43	32	42	27
Flow, m^3	1,098,000	1,798,000	908,000	303,000	4,106,000	9	5	9	5
				1977					
S.S.									
T.P.									
Flow, m^3									

*Sewage treatment plants are considered the only significant point source of total P and suspended solids in the watershed. Blanks indicate data to be collected.

Table 12. Loadings and relative contributions from nonpoint and point sources of pollution for total suspended sediment and total P at 70th St station (413005)

Category	1975		1976	
	Nonpoint	Point	Nonpoint	Point
Loadings				
Water, m^3/yr	90,716,000	4,674,000	79,690,000	4,106,000
Total suspended solids, kg/yr	11,436,500	90,500	9,478,000	78,000
Total P, kg/yr	22,230	13,800	20,900	7,400
Relative Contribution, %				
Water	95	5	95	5
Total suspended solids	99	0.8	99	0.8
Total P	62	38	74	26

which determine the relative amounts of runoff. In urban areas, these primarily involve the nature of the drainage system and the degree of impervious cover. Of lesser importance in the urban environment as compared to the rural environment are soil permeability, slope, ground cover, depression storage, etc. in determining the amounts of runoff. Areas with high amounts of runoff typically export high loads of pollutants. Additionally, there does not appear to be a dilutional effect (low pollutant concentrations) caused by the larger amounts of water. Rather, those stations with high unit amounts of runoff often also have high concentrations of pollutants. This is likely caused by the easy washoff and transport of pollutants in curb and gutter storm sewer systems, and the more intensive scour and transport capacities of larger volumes of water. Stations with natural drainage systems and relatively less runoff (463001, 413625 and 683090) typically generate much lower pollutant loads.

The other aspect of the relative hazard-ranking system, involves the knowledge of those activities, land uses and land covers that affect the concentrations of pollutants. Some of these are long term factors which result in persistently high concentrations, such as lead values from heavy traffic or heavy industry at stations 413615 and 413616 respectively. Inversely, some factors cause persistently low concentrations such as the apparent increased trapping efficiency for suspended solids and lead by natural drainage swales at stations 413625 and 683090 (statistical analysis revealed a .818 correlation between suspended solids and lead loads, indicating lead is predominantly associated with the solids fraction). Other factors affecting pollutant concentrations are short term, either temporal or seasonal. Most visibly are the effects of construction activities on suspended solid concentrations, such as at station 683089 in the spring of 1977. These short term activities may mask longer term differences, as at station 413011 where the impacts of ongoing construction throughout the study period are impossible to separate from non-construction related loads.

It is apparent that no blanket remedial policy based solely on various types of land use is advisable. Rather, remedial measures should be oriented both towards curtailing those short term activities or phenomena which result in high pollutant concentrations, and towards those areas, which

because of their hydraulic and/or other indigenous characteristics, generate long term heavy pollutant loads. It is especially with an eye towards future development that high pollutant loads can effectively and inexpensively be prevented.

iii. Rainfall/Runoff relationships

The effects of storm magnitude and the hydrographic features of several predominant land use areas are illustrated in Table 13. Eight stations, for which both event hydrographs and corresponding on site rainfall information exist, are arranged in decreasing order of percent connected imperviousness (as a percent of total area). The figures listed represent only the percent of runoff generated, and do not consider the effects of rainfall intensities or antecedent soil moisture conditions.

Considered station by station, there is not a consistent increase in the percent of runoff with an increase in storm magnitude. For storms of a given size however, there is a general decrease in percent runoff with a decrease in the percent of connected imperviousness.

The above two observations indicate that runoff is generated largely from impervious surfaces, and that rainfall onto pervious surfaces contributes only a small amount to runoff. The implication supports management practices that would reduce the effective amount of imperviousness, thereby reducing the amount of runoff and the resultant downstream flood hazard.

Table 13. Average runoff with rainfalls of various amounts

STORET number	Imperviousness, %	Connected Imperviousness, %	Number of storms monitored*	Average runoff, % for rainfall amounts of, cm						
				<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.5	>3.5
683089	50	45	19	28	24	37	39	28	30	24
413615	45	43	21	25	21	22	24	22	22	N.A.
413010	54	33	53	12	14	11	16	15	14	20
413034	74	32	14	N.A.	6	8	9	4	15	8
413011	35	28	52	11	17	22	17	31	26	29
413614	18	7	10	12	5	7	N.A.	N.A.	N.A.	14
683090	24	0	6	N.A.	N.A.	6	4	0.4	7	4
463001	5	0	18	N.A.	3	7	0.4	6	6	26

*Total number of storms at each station for which a hydrograph and on-site rainfall information existed.

N.A. No hydrographs or rainfall information were available for storms of this amount.

iv. Relationship of pollutant load to water load

A frequently noted observation cited in the literature is the first flush phenomenon, or the occurrence of highly concentrated pollutants in the early stages of runoff. It has been most commonly noted for areas of combined sewers, where the first overflows carry with them high concentrations of scoured or flushed deposits. We have defined first flush to be when the percent of the total parameter load discharged at any point in an event exceeds the corresponding percent of total water load discharged.

Analysis of the changes in concentrations of suspended solids (S.S.) and total phosphorus (T.P.) over 45 events at six stations indicates that overall, concentrations may or may not shift dramatically or consistently during an event. Concurrently, we find only minimal evidence that a first flush of either S.S. or T.P. occurs routinely (Table 13a). Further, on a site by site basis, there is no apparent association between the degree of first flush and the magnitude of the event, i.e., concentrations do not drop off markedly more over large storms then over small ones.

Analysis between stations indicates that there is not a great deal of variation between them, with the exceptions of stations 683089 and 413615. Although they both have a high percentage of connected imperviousness (44.9 and 43.2% respectively) the former demonstrates the greatest degree of first flush, while the latter demonstrates a lag of pollutant loads behind water load in the early storm stages. These differences may be partially explained by catchment configuration as it relates to the time of travel. At station 683089, the connected portion of the catchment is almost square with a short travel time to the outlet, while at station 413615 the catchment is very elongated resulting in a longer travel time for water from the upper portions of the drainage area.

The implications of these findings are twofold, and are applicable to areas with separate sewers or natural drainage ways. First, storage and treatment of the initial portions of runoff will not remove significantly more pollutants than the percent of the storm that is captured. Second, as the amount of pollutants are closely associated with the amount of runoff, efforts to reduce the amount of runoff will reduce the amount of pollutants generated.

Table 13a. Cumulative parameter load by cumulative water load, % of total discharged*

Cumulative water load	10%	20%	40%	60%	80%
Cumulative suspended solids, average	10.1% ± 8.0	22.0% ± 11.5	45.2% ± 16.3	67.2% ± 17.8	85.8% ± 9.7
Cumulative total phosphorous, average	9.3% ± 7.3	20.5% ± 11.1	41.9% ± 14.6	63.0% ± 14.9	82.8% ± 8.1

*Results are based on analysis of 53 of the most closely monitored events. The integration program was used to calculate the cumulative parameter loads. For these calculations, the end of the storm (100% of the water load discharged) is considered to be the time of the last sampling.

v. Simulated unit loading data and hazard ranking of land uses

Simulated loadings of suspended solids, total phosphorus and lead have been used to weight the pollution contribution of various land uses in the Menomonee River watershed. The simulated loadings are based on an average soil slope range of 2 to 6%, the prevailing soil type (Ozaukee silt loam), and dust and dirt accumulation and contamination in urban areas based on data from national averages.

The output of the simulation exercises was provided by the LANDRUN model which was developed during this study and reflects the loadings during an average year.

Average ranking factors for suspended sediment, total phosphorus and lead, based on the 12 major land use categories in the Menomonee River watershed are given in Table 14. These factors reflect approximate pollutant generation at the sources and are given in units of kg/ha/yr.

The ranking factors for each pollutant for each land use category are applied in Table 15. The loading factors presented were obtained by comparing the sum of the products of the ranking factors times the fraction of land use in the Menomonee River watershed with the actual loadings measured at the river mouth (70th St.).

A relative degree of hazard scale (impact on water quality) was assigned to each land use by utilizing an approximate logarithmic scale of loading factors. Table 15 and Figs. 2, 3 and 4 in graph form provide data showing the actual amount and percent contribution of each land use to the total loadings for each of the three pollutants at the river mouth. It should be pointed out that developing urban areas, although representing only 2.6% of the total area of the watershed, contribute ca 37% and 48% respectively, of the suspended solids and total phosphorus at the river mouth.

The relative degrees of hazard for the land use activities are interpreted on the basis of a logarithmic scale. Thus, for total suspended solids as an example, the loading factor at the river mouth for wetlands (116 kg/ha/yr) is ca 100 times greater than that for forested land and woodlots (1.5 kg/ha/yr) and is assigned a hazard degree ranking of 3.

The highest unit loading factors for suspended solids and total phosphorus were for feedlot operations when expressed on a kg/ha/yr basis. Only developing urban land areas approached the same order of magnitude

Table 14. Ranking factors (potential erodibility at source) for the land use categories designated in the Menomonee River watershed

Land use category	Ranking factors, kg/ha/yr		
	Sus. solids	Total phos.	Lead
1. Industrial	5,100	4.46	6.9
2. Commercial	3,450	1.51	13.2
3. High-density residential	3,650	2.77	5.6
4. Medium-density residential	3,100	2.46	4.2
5. Low-density residential	650	1.05	0.48
6. Land under development	43,700	78.7	0.10
7. Row crops	1,780	3.19	0
8. Pastures and small grains	1,310	2.3	0
8a. Park and recreation*	460	0.81	0
9. Forested lands and woodlots	15	0.03	0
10. Wetlands	1,160	2.1	0
11. Feedlots	69,600	250	0
12. Landfills and dumps**	-	-	-

*Park and recreation included in land use category no. 8 in Table 1 is segregated.

**Excluded because this land use is likely to have a greater impact on groundwater than on surface water.

Table 15. Relative degree of hazard, loading factors, loading at river mouth for suspended sediment, total phosphorus and lead for various categories of land use in the Menomonee River watershed utilizing unit load values at the 70th St (413005) monitoring station

Land use category*	Unit loads** at river mouth, kg/ha/yr	Loading at river mouth kg/yr/land use	Loading at river mouth % land use	Area for land use, %	Relative degree of hazard
		SUSPENDED SEDIMENT			
9	1.5	3,000	0.03	5.6	1
8a	46	73,000	0.68	4.4	2
5	65	271,000	2.5	11.8	2
10	116	124,000	1.2	3.0	3
8	131	1,096,000	10.2	13.7	3
7	178	856,000	8.0	23.7	3
4	310	1,393,000	12.9	12.7	3.5
2	345	2,257,000	21.0	18.5	3.5
3	365	157,000	1.5	1.2	3.5
1	510	312,000	3.0	1.7	3.5
6	4,370	4,000,000	37.2	2.6	5.5
11	6,960	223,000	2.1	0.1	5.5
		10,765,000		99.1***	
		TOTAL PHOSPHORUS			
9	0.003	9	0.06	5.6	1
8a	0.08	128	0.87	4.4	2
5	0.10	438	3.0	11.8	2.5
2	0.15	988	6.7	18.5	2.5
10	0.21	225	1.5	3.0	2.5
8	0.23	1,925	13.1	13.7	2.5
4	0.25	1,105	7.5	12.7	2.5
3	0.28	119	0.81	1.2	2.5
7	0.32	1,443	9.8	23.7	2.8
1	0.45	273	1.9	1.7	3.0
6	7.9	7,201	49.0	2.6	4.0
11	25	800	5.5	0.1	5.0
		14,654		99.1***	
		LEAD			
9	0	0	0	5.6	0
8a	0	0	0	4.4	0
8	0	0	0	13.7	0
10	0	0	0	3.0	0
7	0	0	0	23.7	0
11	0	0	0	0.1	0
6	0.010	10	0.09	2.6	1
5	0.048	200	1.8	11.8	2
4	0.42	1,887	16	12.7	3
3	0.56	240	2.1	1.2	3
1	0.69	428	3.8	1.7	3
2	1.32	8,635	76	18.5	3.5
		11,400		99.1***	

*Definitions of land category numbers are shown in Table 1. Park and recreation included in category 8--pastures and small grains--segregated. Category 12--landfill and dumps--not estimated since it is expected to impact more on groundwater. Category 13--water areas--not included.
**10% delivery ratio was assumed from potential transportable pollutants shown in Table 14.
***Landfill and water areas comprise 0.9% of area of basin.

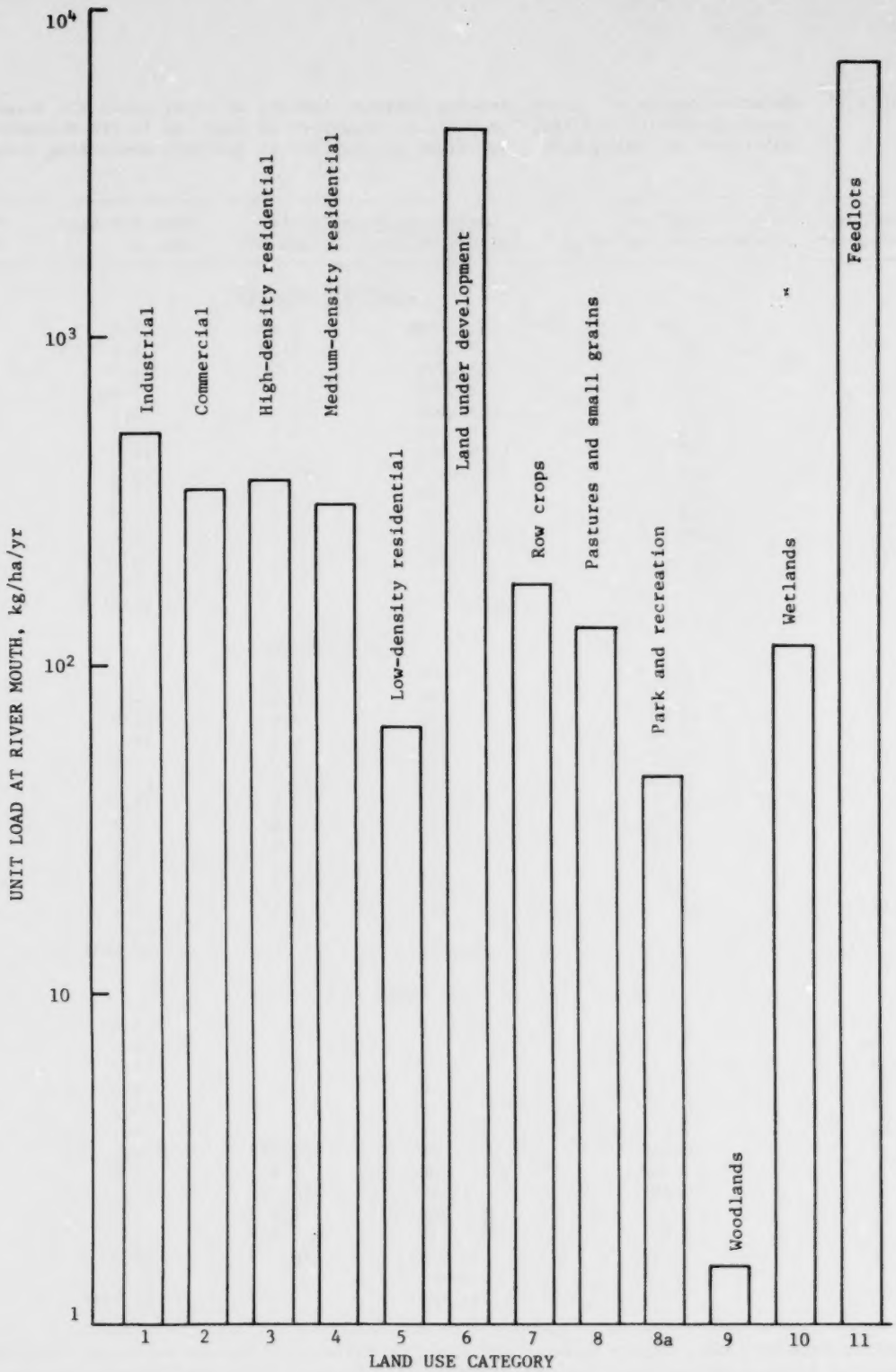

Fig. 2. Simulated unit loadings of suspended sediment for principal land use categories at the mouth (70th St.) of the Menomonee River (413005).

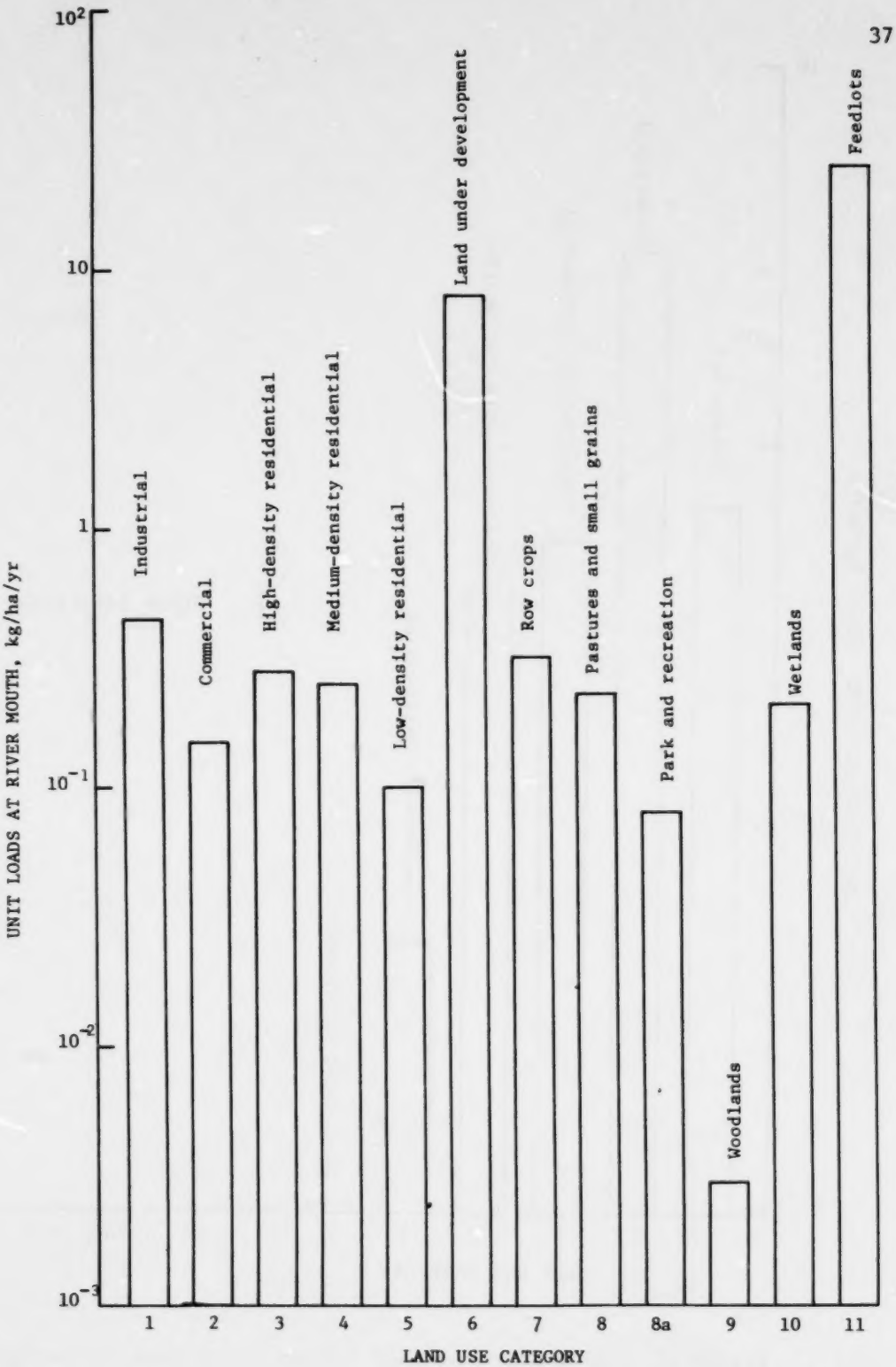

Fig. 3. Simulated unit loadings of total P for principal land use categories at the mouth (70th St.) of the Menomonee River (413005).

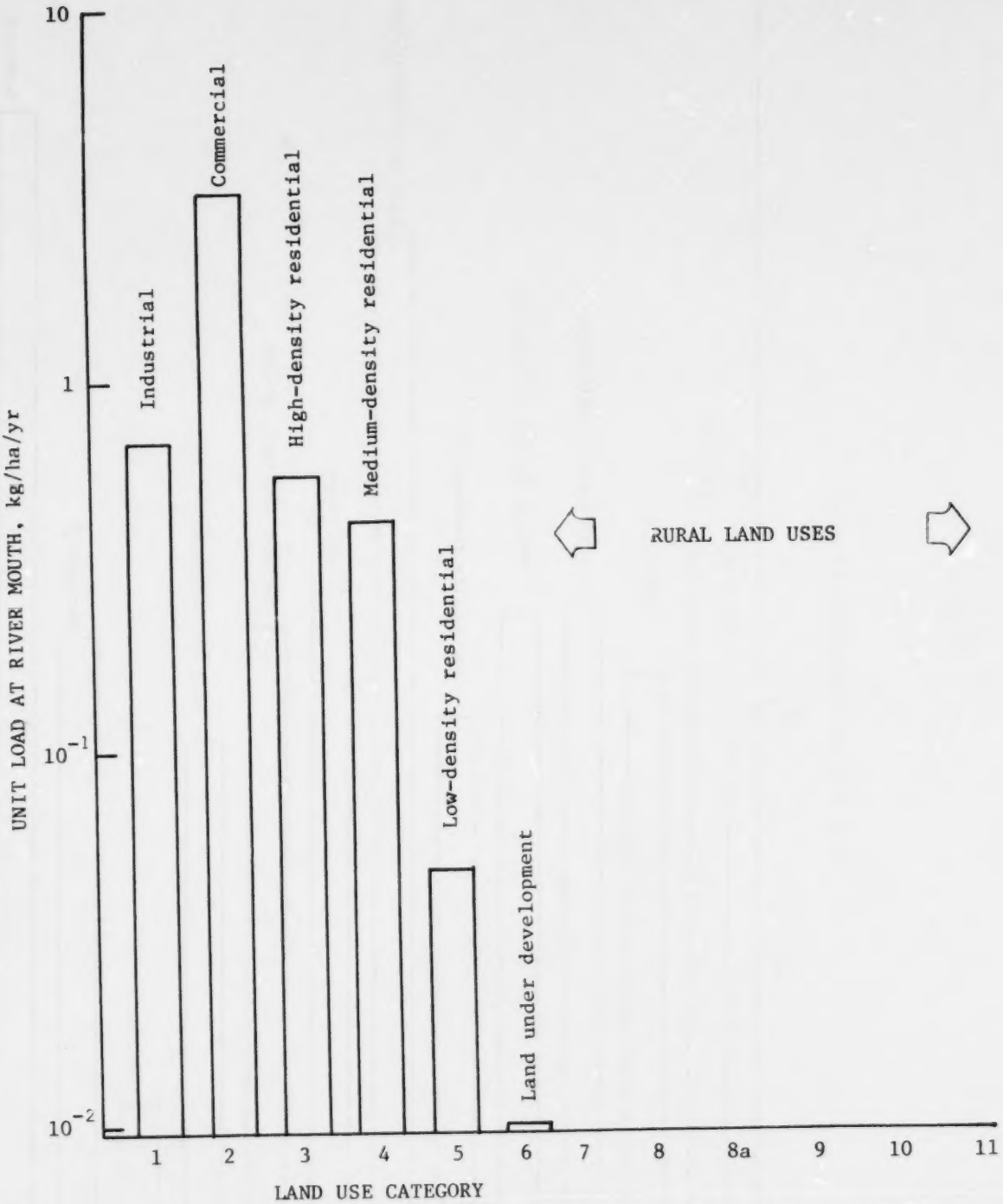

Fig. 4. Simulated unit loadings of lead for principal land use categories at the mouth (70th St.) of the Menomonee River (413005).

for the loading factors. However, an examination of Table 15 clearly shows that feedlot operations do not represent a significant contribution to the total river mouth loadings for suspended solids and total phosphorus. Thus, when considering the relative degree of hazard, unit area loading factors and percent loading at the river mouth for each of these pollutants, care must be taken in interpreting the significance of any given land use activity. However, the issue is more straightforward when considering lead. The unit area loading for lead is highest in commercial areas. About 80% of the total river mouth loading of lead originates from commercial property, traffic corridors and transportion system activities. Thus, the commercial land use category has the highest degree of hazard, the highest unit loading and by far the greatest contribution to the total river mouth loading. It should also be mentioned that the commercial land use category (including transportation) accounts for ca 19% of the total area of the Menomonee River watershed. This is the third highest areal land use category (highest urban category) after row crops and pastures.

By comparing river mouth loadings with loadings generated at the source, it was possible to estimate approximate delivery ratios for the Menomonee River watershed. The delivery ratios for suspended sediment, total phosphorus and lead were of the order of 10%, but the weakness of some of the assumptions make it difficult to establish a precise numerical value. The delivery ratios are based on comparisons of the monitoring data for a limited time frame with simulated loadings based on national averages. Therefore, the delivery ratios represent rough estimates and are not absolute values.

However this information could have important consequences for the development of management strategies since a reduction of about 50% in suspended solids and total phosphorus might be achieved by treatment of about 5% of the land area. Similarly, about 80% reduction in lead reaching the river mouth might be achieved by treatment of 15 to 20% of the land area. Thus in the development of remedial strategies, decisions must be made on the relative importance of different parameters as they impact on lake quality and use. Further implications of this information is discussed in the section dealing with usefulness of findings on the Great Lakes basin scale.

D. PHYSICAL CHARACTERISTICS OF THE WATERSHED

The Menomonee River watershed features a variety of land uses. Land use inventories for 1970 and 1975 indicate that the lower part of the watershed is highly urbanized while the upper portion is essentially rural. Greater changes in land use would be expected to occur in the upper watershed because of urbanization brought about by increasing population.

The kinds and amounts of land-derived pollutants depend on the land use as affected by man's activities, imperviousness, soil type, degree of erodibility, and slope. The distance of the pollution source to the stream has a considerable influence on the delivery of the pollutants generated during runoff and erosional processes. While slope and soil type are the predominant factors in rural watersheds, the main factor governing inputs from urban and urbanizing watersheds is likely to be the degree of imperviousness of the land surface.

The major soil types and some physical characteristics of the 48 subwatersheds in the Menomonee River watershed are presented in Table 16. The majority of the soils are silt loams. The two soils that are predominant and widely distributed in the watershed are Ozaukee sil and Mequon sil. The average slope for most of the soils range from 1 to 6% which corresponds to slopes of nearly level to gently sloping. Most of the soils have an erodibility factor of 0.35. The degree of imperviousness associated with the subwatersheds ranges from three to about 65% which is indicative of the differences in urban development in the watershed.

Table 16. Soil types and physical characteristics of the 48 subwatersheds of the Menomonee River watershed for use in the LANDRUN model

Trib. subwatershed No.	Area (ha)	Principal soil type,* %	Average slope, %	Perm., cm/hr	Erodibil. factor**	Imperv.,+ %
		Upper Menomonee River - No. 673001***				
12A	430	Palms mucky peat-20	1	9.50	0.25	13
		Mixed Ozaukee and Mequon sil-18	4	4.20	0.35	
		Theresa sil-18	3	4.20	0.35	
		Hochheim sil-15	5	4.20	0.45	
12B	1,200	Theresa sil-25	4	4.20	0.35	6.8
		Mayville sil-20	3	4.20	0.35	
		Hochheim sil-15	7	4.20	0.35	
		Pella sil-10	1	9.50	0.35	
12C	570	Theresa sil-21	4	4.20	0.35	8.3
		Hochheim sil-14	7	4.20	0.35	
		Palms mucky peat-12	1	9.50	0.25	
		Lamartine sil-10	2	4.20	0.35	
		Houghton mucky peat-10	1	9.50	0.25	
12D	980	Theresa sil-20	4	4.20	0.35	2.5
		Pella sil-14	1	9.50	0.35	
		Hochheim sil-12	6	4.20	0.35	
12E	1,592	Ozaukee sil-40	5	4.20	0.28	
		Palms mucky peat-14	1	9.50	0.25	
		Ashkum [illegible]cl-10	2	1.25	0.28	1.3
		Upper Menomonee River - No. 683002				
10A	620	Ozaukee sil-71	5	4.20	0.35	23
		Palms muck-20	1	9.50	0.25	
		Ashkum sicl-9	1	4.20	0.28	
10B	460	Ozaukee sil-68	2	4.20	0.35	5.2
		Mequon sil-22	3	4.20	0.35	
		Hochheim sil-10	6	4.20	0.35	
10C	500	Ozaukee sil-30	5	4.20	0.35	23
		Knowles sil-16	4	4.20	0.35	
		Ashkum sicl-16	1	1.25	0.28	
		Palms mucky peat-15	1	9.50	0.25	
		Mequon sil-11	2	4.20	0.35	
10D	1,600	Hochheim sil-37	10	4.20	0.35	6.3
		Theresa sil-17	4	4.20	0.35	
10E	850	Ozaukee sil-35	5	4.20	0.35	7.9
		Houghton mucky peat-15	1	9.50	0.25	
		Colwood sil-14	1	4.20	0.35	
		Mequon sil-12	1	4.20	0.35	
		Knowles sil-12	3	4.20	0.35	

Table 16 continued

Trib. No.	subwatershed Area (ha)	Principal soil type,* %	Average slope, %	Perm., cm/hr	Erodibil. factor	Imperv.,+ %
		Upper Menomonee River - No. 683001				
7A	890	Ozaukee sil-60	6	4.20	0.35	21
		Mequon sil-23	3	4.20	0.35	
7B	820	Ozaukee sil-60	6.5	4.20	0.35	11
		Mequon sil-17	2	4.20	0.35	
		Palms muck-13	1	9.50	0.25	
		Ashkum sicl-10	1	1.25	0.28	
7C	720	Ozaukee sil-65	4	4.20	0.35	16
		Mequon sil-25	3	4.20	0.35	
7D	1,400	Ozaukee sil-55	5	4.20	0.35	17
		Mequon sil-32	3	4.20	0.35	
7E	300	Ozaukee sil-55	5	4.20	0.35	24
		Martinton sil-17	2	4.20	0.35	
		Mequon sil-12	2	4.20	0.35	
7F	830	Ozaukee sil-50	5	4.20	0.35	12
		Mequon sil-25	3	4.20	0.35	
7G	1,300	Ozaukee sil-75	5	4.20	0.35	9.7
		Mequon sil-13	1	4.20	0.35	
7H	230	Ozaukee sil-100	4	4.20	0.28	35
		Little Menomonee River - No. 463001				
11A	527	Ozaukee sil-50	3	4.20	0.35	4.6
		Mequon sil-13	1	4.20	0.25	
		Ogden muck-10	1	9.50	0.35	
11B	852	Ozaukee sil-50	3	4.20	0.35	4.6
		Mequon sil-10	1	4.20	0.35	
11C	766	Ozaukee sil-44	3	4.20	0.35	3.1
		Ogden muck-14	1	9.50	0.35	
		Pella sil-11	1	9.50	0.35	
		Little Menomonee River - No. 413011				
9	553	Ozaukee sil-39	3	4.20	0.35	44
		Mequon sil-20	3	4.20	0.35	
		Little Menomonee River - No. 413008				
8A	600	Ozaukee sil-67	5	4.20	0.35	27
		Mequon sil-22	3	4.20	0.35	
8B	840	Ozaukee sil-68	5	4.20	0.35	12
		Mequon sil-20	2	4.20	0.28	
		Ashkum sicl-12	4	4.20	0.35	
8C	1,010	Ozaukee sil-45	4	4.20	0.35	10.5
		Sebawa sil-28	1	4.20	0.35	
		Mequon sil-13	2	4.20	0.35	

Trib. subwatershed No.	Area (ha)	Principal soil type,* %	Average slope, %	Perm., cm/hr	Erodibil. factor**	Imperv.,+ %
		Lower Menomonee River - No. 413007				
6A & 6C	1,457	Ozaukee sil-68	4	4.20	0.35	31
6B	1,308	Ozaukee sil-39	2.7	4.20	0.35	38
6D & 6F	1,109	Ozaukee sil-47	2	4.20	0.35	12
6E	975	Ozaukee sil-57	4.3	4.20	0.35	20
		Mixed Ozaukee sil and Houghton muck-29	3.5	4.20	0.35	
		Lower Menomonee River - No. 413006				
4A	790	Ozaukee sil-33	1	4.20	0.35	51
4B, 4C & 4D	1,991	Ozaukee sil-92	2.5	4.20	0.35	42
		Lower Menomonee River - No. 413005				
3A	326	++				47
3B & 3H	2,339	Ozaukee sil-61	2.5	4.20	0.35	50
3C	224	Ozaukee sil-44	4	4.20	0.35	45
		Mequon sil-11	3	4.20	0.35	
3D	605	Ozaukee sil-36	4	4.20	0.35	50
		Mequon sil-25	3	4.20	0.35	
3E	320	Ozaukee sil-29	5	4.20	0.35	44
		Mequon sil-18	3	4.20	0.35	
		Alluvial land-9	1	4.00	0.44	
3F	500	Ozaukee sil-65	5	4.20	0.35	45
		Mequon sil-30	3	4.20	0.35	
3G	142	Mequon sil-26	1	4.20	0.35	52
		Ozaukee sil-10	3	4.20	0.35	
		Lower Menomonee River - No. 413010				
5	178	++				54
		Lower Menomonee River - No. 413099				
2	182	++				54
		Lower Menomonee River - No. 413004				
1A	1,142	++				66
1B	388	++				56
19	304	++				54

*Location of monitoring stations is given in Fig. 1 and Table 2.
**Soil types occupying more than 10% of subwatershed area are included.
***This is the K factor in the Universal Soil Loss Equation; as number increases the susceptibility to erosion increases.
+Imperviousness of whole subwatershed based on 1975 Land Uses Inventory by SEWPRC.
++No soil mapped.

E. CHARACTERIZATION OF SOILS AND BOTTOM AND SUSPENDED SEDIMENTS

The surface area of soil and sediment particles is determined largely by particle size, i.e., the surface area increases very rapidly as particle size decreases. In turn, the surface area determines the quantity of pollutants that can be adsorbed by soil and sediment particles. Thus, the incursion of soil particles of large diameter (sand-sized particles) into water-courses will be less detrimental than small diameter particles (clay-sized particles). In determining the advantages and disadvantages of alternate sediment control measures it is important that the fine materials be given prime consideration. This section describes the particle size distribution and composition of the major soil types in the Menomonee River watershed and the bottom and suspended sediments being carried and deposited by the Menomonee River (Tables 17 and 18). This information--where combined and compared with information from other pilot watersheds--should assist those persons having responsibility for extrapolating the pilot watershed information to the Great Lakes basin and for evaluating the advantages and disadvantages of alternative remedial measures.

Preliminary results indicate a significant enrichment of clay-sized particles in the suspended sediment; about a three-fold increase over that of the surrounding soils (Table 17). The effect of clay enrichment on pollutant transport can be appreciated by estimating the specific surface of the soils and the suspended sediment. The average specific surface calculated for the soils and suspended sediment are 74 and 171 m^2/g, respectively; an increase in potential pollutant transport by more than two-fold. Particle size distribution (PSD) was determined by ultrasonic dispersion of soils or sediment without prior removal of organic matter. The ultrasonically-separated particles were used for the analysis of total P and metals (Tables 17 and 18). This is the preferred method of dispersion if analysis of the above parameters is desired. Contamination through contact of metal containers and addition of chemical additives as used in the conventional PSD analysis is avoided. Determination of PSD in suspended sediment by the U.S. Geological Survey using a chemical dispersant after organic matter oxidation also showed high amounts of claysized particles (Table 19).

Table 17. Particle size distribution and total P concentrations in various size fractions of soils and bottom and suspended sediments in the Menomonee River watershed

Sample/sample location*	Particle size distribution** %			Total P, µg/g		
	Sand	Silt	Clay	Sand	Silt	Clay
SOILS* **						
Ozaukee silt loam	24	57	19	119	241	2,757
Mequon silt loam	35	36	29	186	443	2,668
Hochheim silt loam	29	44	27	82	154	1,821
Ashkum silty clay loam	21	44	35	491	397	2,775
Pella silt loam	14	49	37	426	290	1,517
Theresa silt loam	22	62	16	79	128	2,336
BOTTOM SEDIMENT						
Upper Menomonee River						
Friestad	36	37	27	258	561	1,434
River Lane (673001)	65	19	16	108	490	1,564
Menomonee Falls	27	30	43	365	570	1,688
Northern Crossway	67	19	14	180	894	5,529
Lily Creek	21	46	33	872	1,949	4,214
Dretzka Creek	30	23	47	529	700	5,115
124th St (683001)	18	45	37	641	1,839	2,943
Little Menomonee River						
Donges Bay Road (463001)	59	25	16	149	394	2,092
County Q Road	25	25	50	404	524	1,557
Road F near Road B	64	19	17	81	290	1,782
Appleton Ave (413008)	17	32	51	154	200	426
Lower Menomonee River						
Capitol Drive	46	28	26	128	210	2,203
70th St (413005)	80	8	5	141	418	1,584
Falk Corporation (413004)	46	33	21	289	1,257	2,683
SUSPENDED SEDIMENT						
Upper Menomonee River						
River Lane (673001)	n.d.	18	82	n.a.	1,030	4,016
Pilgrim Road (683002)	n.d.	19	81	n.a.	1,366	2,023
124th St (683001)	n.d.	28	72	n.a.	903	2,142
Little Menomonee River						
Donges Bay Rd (463001)	n.d.	9	91	n.a.	760	1,795
Noyes Creek (413011)	n.d.	6	94	n.a.	286	1,109
Appleton Ave (413008)	n.d.	17	83	n.a.	402	1,061
Lower Menomonee River						
Underwood Creek (413007)	n.d.	18	82	n.a.	724	1,376
Honey Creek (413006)	n.d.	20	80	n.a.	864	1,705
70th St (413005)	n.d.	18	82	n.a.	640	1,414
Schoonmaker Creek (413010)	n.d.	27	73	n.a.	770	2,179
Falk Corporation (413004)	n.d.	17	83	n.a.	873	1,148

*STORET numbers of major monitoring stations in parentheses

**Samples dispersed by ultrasonic treatment without prior removal of organic matter. Clay-size fraction is < 4 µm.

***Approximately 100 soil types have been mapped in the Menomonee River watershed. Total area of watershed is 35,285 ha of which 26,712 ha are mapped by soil type. The soils listed constitute 70% of the area mapped as soil.

n.d. Not detected

n.a. Sand fraction not present

Table 18. Metal* concentrations in various size fractions of soils and bottom and suspended sediments in the Menomonee River watershed

Sample/sample location**	Metal, µg/g								
	Pb			Cd			Cu		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
SOILS* **									
Ozaukee silt loam	n.d.	9.5	58	n.d.	0.16	0.78	2.3	17	90
Mequon silt loam	4.7	11	39	n.d.	0.25	0.73	4.0	15	82
Hochheim silt loam	5.5	9.8	56	n.d.	0.11	0.35	1.8	7.3	41
Ashkum silty clay loam	9.0	14	36	n.d.	0.53	1.24	2.0	27	106
Pella silt loam	9.8	10	39	n.d.	0.23	0.81	1.9	8.2	44
Theresa silt loam	n.d.	6.0	55	n.d.	0.12	0.44	2.1	4.8	36
BOTTOM SEDIMENT									
Upper Menomonee River									
Friestad	4.1	7.8	25	n.d.	0.20	1.3	2.1	9.8	52
River Lane (673001)	7.4	16	41	n.d.	n.d.	0.98	1.9	8.2	44
Menomonee Falls	12	18	55	n.d.	n.d.	0.54	3.6	7.1	38
Northern Crossway	32	101	512	0.08	0.72	3.2	4.1	27	149
Lily Creek	36	64	438	n.d.	0.31	2.9	9.4	11.8	145
Dretzka Creek	17	55	334	0.11	0.59	2.5	4.1	20	122
124th St (683001)	14	33	208	n.d.	0.26	1.7	6.7	17	85
Little Menomonee River									
Donges Bay Road (463001)	2.5	7.3	36	0.06	0.21	1.1	2.4	8.5	48
County Q Road	9.6	17	25	n.d.	n.d.	0.86	2.8	11	36
Road F near Road B	4.1	16	65	0.06	0.45	1.6	1.7	8.1	48
Appleton Ave (413008)	20	21	41	n.d.	0.16	0.58	3.0	6.6	29
Lower Menomonee River									
Capitol Drive	32	35	115	0.19	0.44	1.8	6.6	13.8	108
70th St (413005)	16	92	487	0.07	0.52	3.8	5.7	42	110
Falk Corporation (413004)	170	412	1,439	1.88	4.98	33	102	219	475
SUSPENDED SEDIMENT									
Upper Menomonee River									
River Lane (673001)	n.a.	n.d.	83	n.a.	n.d.	2.4	n.a.	29	37
Pilgrim Road (683002)	n.a.	50	244	n.a.	n.d.	n.d.	n.a.	22	51
124th St (683001)	n.a.	60	204	n.a.	n.d.	0.90	n.a.	19	71
Little Menomonee River									
Donges Bay Road (463001)	n.a.	n.d.	43	n.a.	n.d.	0.34	n.a.	20	47
Noyes Creek (413011)	n.a.	139	166	n.a.	n.d.	0.58	n.a.	41	41
Appleton Ave (413008)	n.a.	31	63	n.a.	n.d.	0.37	n.a.	8.3	38
Lower Menomonee River									
Underwood Creek (413007)	n.a.	348	515	n.a.	n.d.	1.7	n.a.	40	78
Honey Creek (413006)	n.a.	158	333	n.a.	0.81	1.4	n.a.	39	76
70th St (413005)	n.a.	125	165	n.a.	n.d.	0.88	n.a.	50	70
Schoonmaker Creek (413010)	n.a.	967	1,513	n.a.	n.d.	4.4	n.a.	50	104
Falk Corporation (413004)	n.a.	104	118	n.a.	0.77	0.75	n.a.	37	69

*Samples have been analyzed for Zn, Fe, Cr, Ni and Mn

**STORET numbers of major monitoring stations in parentheses

***Approximately 100 soil types have been mapped in the Menomonee River watershed. Total area of the watershed is 35,285 ha of which 26,712 ha are mapped by soil type. The soils listed constitute 70% of the total area mapped as soil.

n.d. Not detected

n.a. Sand fraction not present

Table 19. Particle size distribution of suspended sediment in the Menomonee River watershed

Sample location*	Date collected	Time collected	Instantaneous discharge, CMS	Position on hydrograph	Suspended sediment, mg/l	Particle size distribution, **% Sand	Silt	Clay
Upper Menomonee River								
River Lane (673001)	2-4-76	1540	0.10	Normal winter flow	54	28	40	32
	8-31-76	1545	0.06	Steady flow	26	3	22	75
Pilgrim Road (683002)	8-31-76	1205	0.06	Falling stage	16	1	16	83
	9-19-76	1950	0.40	Tail end of event	34	1	21	78
124th St (683001)	2-18-76	1515	9.5	Rising stage	267	4	38	58
	7-30-76	2355	1.4	Falling stage	213	1	18	81
	7-31-76	0450	2.5	Peak	260	1	32	67
	7-31-76	1555	0.57	Falling stage	80	0	22	78
	9-15-76	1050	0.15	Peak	133	4	41	55
Little Menomonee River								
Donges Bay Road (463001)	3-29-76	0850	1.87	Falling stage	224	7	33	70
	7-30-76	2135	0.15	Rising stage	221	1	27	72
	8-31-76	1430	0.004	Rising stage	19	5	43	52
Noyes Creek (413011)	3-12-76	1445	2.8	Falling stage	1,740	2	45	53
	7-28-76	0800	0.12	Rising stage	299	2	51	47
	7-28-76	1150	0.18	Falling stage	64	2	22	76
	9-19-76	1630	0.05	Rising stage	66	2	30	68
Appleton Ave (413008)	2-18-76	1635	3.7	Falling stage	247	2	22	76
	7-28-76	1200	0.28	Rising stage	129	2	29	69
	7-30-76	2130	2.5	Rising stage	1,140	0	28	72
	7-31-76	0345	2.5	Falling stage	1,220	0	16	84
	9-15-76	1215	0.02	Steady flow	18	1	15	84
Lower Menomonee River								
Underwood Creek (413002)	2-18-76	1420	3.5	Falling stage	***	3	17	80
	2-25-76	1435	1.9	Rising stage	380	4	35	61
Honey Creek (413010)	2-9-76	1605	0.37	Rising stage	1,020	0	5	95
	2-12-76	1503	2.3	Peak	796	6	38	56
	7-28-76	0850	3.0	Rising stage	389	6	52	42
	7-28-76	1220	3.9	Falling stage	31	3	27	70
	9-19-76	1815	1.5	Approaching peak	226	5	36	59
	9-19-76	2040	1.1	Falling stage	98	2	24	74
Schoonmaker Creek (413010)	2-12-76	1300	0.54	Approaching peak	551	2	13	85
	3-12-76	1446	0.20	Rising stage	330	0	29	71
	7-28-76	0810	0.19	Approaching peak	485	1	49	50
	7-28-76	0900	0.17	Just after peak	222	0	40	60
	9-9-76	0235	2.4	Peak	833	14	52	34
	9-9-76	0250	2.3	Just after peak	376	14	44	42
	9-9-76	0305	0.93	Falling stage	183	8	38	54
70th St (413005)	2-18-76	1230	13.9	Falling stage	***	7	34	59
	3-5-76	1355	55.3	Falling stage	179	24	20	56
	3-12-76	1610	19.0	Rising stage	344	9	27	64
	3-12-76	1820	22.4	Rising stage	257	4	17	79
	7-28-76	1111	5.0	Falling stage	357	2	47	51
	7-28-76	1530	2.0	Falling stage	76	4	19	77
	7-28-76	1550	1.9	Falling stage	66	3	21	76
	7-30-76	2330	14.3	Approaching peak	515	5	41	54
	7-31-76	2030	1.3	Falling stage	143	0	6	94
Falk Corporation (413004)	7-28-76	1140	0.42	Rising stage	233	0	24	76

*STORET numbers of major monitoring stations are in parentheses.

**Samples dispersed with Na hexametaphosphate after oxidation of organic matter content. Clay size fraction is < 4 μm as determined by U.S. Geological Survey.

***No data.

Total P and trace metals associated with soils and sediments are concentrated in the clay-size fraction (Tables 17 and 18). The amounts of these elements in the various fractions are in the order of sand<silt<clay. The distribution of total P and Pb in the various fractions is given in Table 20. About 70 to 90% of the total P and Pb is contained in the clay-size fraction. An indication of Pb enrichment in the bottom sediments is evident for the portions of the river adjacent to more urbanized portions of the watershed. Such accumulation could be due to localized pollution.

In the past, insufficient consideration has been given to the importance of particle size distribution in evaluating pollutant carrying capacity of sediments. Using the ultrasound dispersion method, it is possible to maintain the particles with their associated pollutants intact, thereby allowing a determination of how much of which pollutant is associated with a particular particle size fraction.

Because soil and sediment particles form aggregates, dispersion is essential to determine distribution of primary particles. However, some aggregates will be more difficult to disperse than others and these will be more likely to remain as aggregates during the buffeting that they undergo in their transport from the land to the lake. Thus, stable aggregates which may have high clay contents--are likely to behave as much larger particles in the aquatic system. They will expose less surface area and will sediment more quickly than particles dislodged from unstable aggregates and the nutrients and pollutants sorbed by the particles will be less available to the biota. This may be an indirect method of evaluating availability. The soil or sediment could be shaken with water to simulate its transport in the aquatic system and particle size distribution determined (Table 21). A similar sample could be dispersed completely by ultrasound and particle size distribution determined. The ratio of these two size distributions would provide a number which would measure the ease of dispersibility of a particular soil or sediment (Table 22). This number would then serve as a ranking factor for nutrient or pollutant availability to the lake biota.

Table 20. Distribution of total P and Pb in various size fractions in soils and sediment

Fraction	Distribution,* %	
	Total P	Pb
Soils		
Sand	7	9
Silt	16	25
Clay	77	66
Bottom Sediment		
Sand	13	11
Silt	19	16
Clay	68	73
Suspended Sediment		
Sand	0	0
Silt	9	13
Clay	91	87

*Average of all soils and sediments. Values are obtained by using the equation:

$$\% \text{ Distribution} = \frac{(\text{Mean } \% \text{ fraction})(\text{Mean concentration in each fraction})}{\Sigma(\text{Mean } \% \text{ fraction})(\text{Mean concentration in each fraction})} \times 100$$

Table 21. Dispersability, by shaking, of soils in the Menomonee River watershed

Time of shaking (hr)	Fraction,*%	Soils					
		Ozaukee sil	Mequon sil	Hochheim sil	Ashkum sicl	Pella sil	Theresa sil
1	Sand	51.8	63.3	56.8	45.2	51.4	37.7
	Silt	46.3	35.3	41.2	52.4	45.6	60.2
	Clay	1.9	1.4	2.0	2.4	3.0	2.1
4	Sand	48.4	64.6	55.5	52.7	50.6	43.0
	Silt	48.0	32.3	40.3	43.3	44.6	54.0
	Clay	3.6	3.0	4.2	4.0	4.8	3.0
16	Sand	37.6	58.9	46.6	45.6	42.3	34.3
	Silt	57.4	37.3	46.8	47.9	50.7	61.6
	Clay	5.0	4.4	6.6	6.4	7.0	4.1
32	Sand	41.7	49.8	46.0	45.2	32.7	35.3
	Silt	52.2	42.3	45.8	46.5	58.6	60.2
	Clay	6.1	7.9	8.2	8.3	8.7	4.6
64	Sand	39.8	54.1	44.8	39.5	32.9	35.6
	Silt	52.5	34.5	44.4	50.2	56.7	58.2
	Clay	7.7	11.4	10.8	10.2	10.4	6.1

*Sand: 2,000 - 62 μm, silt: 62 - 4 μm, clay: < 4 μm

Table 22. Dispersability of clay-size particles by shaking and ratio of clay-size particles dispersed by shaking and ultrasonic treatment

Time of shaking (hr)	Soils					
	Ozaukee sil	Mequon sil	Hochheim sil	Ashkum sicl	Pella sil	Theresa sil
	Clay Dispersed, %					
1	1.9	1.4	2.0	2.4	3.0	2.1
4	3.6	3.0	4.2	4.0	4.8	3.0
16	5.0	4.4	6.6	6.4	7.0	4.1
32	6.1	7.9	8.2	8.3	8.7	4.6
64	7.7	11.4	10.8	10.2	10.4	6.1
	Ratio (shaking/ultrasonic)					
1	0.10	0.05	0.07	0.07	0.08	0.13
4	0.19	0.10	0.16	0.11	0.13	0.19
16	0.26	0.15	0.24	0.18	0.19	0.26
32	0.32	0.27	0.30	0.24	0.24	0.29
64	0.40	0.39	0.40	0.29	0.28	0.38

11. DATA ANALYSIS AND INTERPRETATION FOR THE MENOMONEE RIVER WATERSHED

Section 11 of this document was formatted to include that data and information which is particular to the individual pilot watershed investigation. An overland flow simulation model was developed for this program and was calibrated and verified in the Menomonee River watershed. Its usefulness in predicting loadings for other areas, e.g., Toledo, is presently under examination. A groundwater study has been conducted to measure the quality of groundwater in the basin and to develop loading rates of groundwater to the river. A model which simulates the transport of conservative ions through a one-dimensional groundwater system is currently being tested and will be used to model the movement of chloride in several vertically-oriented cross-sections. In order to relate groundwater quality to land use, a series of land use/groundwater contaminant-potential maps are being prepared.

Computation of atmospheric loadings of nutrients and toxic elements for the basin is underway and attempts will be made to segregate sources of these materials. The use of aerial imagery to classify land cover has been evaluated and the potential for the use of this methodology for the transfer of Menomonee River information to other urban areas has been tested for Toledo, Detroit and Rochester. Attempts to find a biological indicator of pollution in a river system has, to this point, met with limited success.

The information gathered in Sections 10 and 11 of this report will be compared with data from other pilot watershed investigations which, in turn, will allow assessment of recommendations on a basin-wide basis.

A. LANDRUN MODEL

A variety of models is available for modeling runoff from urban and nonurban areas, but only a few include pollutant transport. Of the available models most are either general hydrologic models estimating runoff quantity from rainfall excess or models that are used for the design of stormwater overflows in sanitary sewers. It was felt that the development of a medium-sized hydrologic and sediment transport model would best meet Task C objectives. The model, under the working code LANDRUN, was developed to describe the washoff of pollutants from land surfaces. The model can be used to describe the washoff of pollutants in watersheds under existing land use conditions or under predicted future conditions.

i. The LANDRUN model and its applicability to watershed studies

The LANDRUN model is a dynamic hydrologic transport model which transforms precipitation into surface runoff, interflow and groundwater aquifer recharge quantity and quality. A schematic conceptual flow diagram of the model is shown in Fig. 5. Most of the model parameters and some inputs, such as imperviousness, are related to land use within the modeled watershed.

A soil adsorption model applicable to phosphorus, pesticides and toxic elements is incorporated as a subroutine into LANDRUN. The parameters of the model are related to such soil characteristics as pH, and clay and organic matter contents and the inputs are infiltration rate, soil moisture content, evapotransportation, fertilizer application and amount of the modeled substance removed by growth and harvesting of crops. The output from the subroutine is the amount of pollutants adsorbed on top soil particles, quantity of dissolved pollutants removed from the top soil and the amount of dissolved pollutants in the interflow and groundwater recharge.

As mentioned earlier, the model can be used to predict the washoff of pollutants from the land surface in a watershed under existing or future land use conditions. Use of the model frees the investigator from temporal constraints in that long term rainfall data can be used to generate washoff for an "average year".

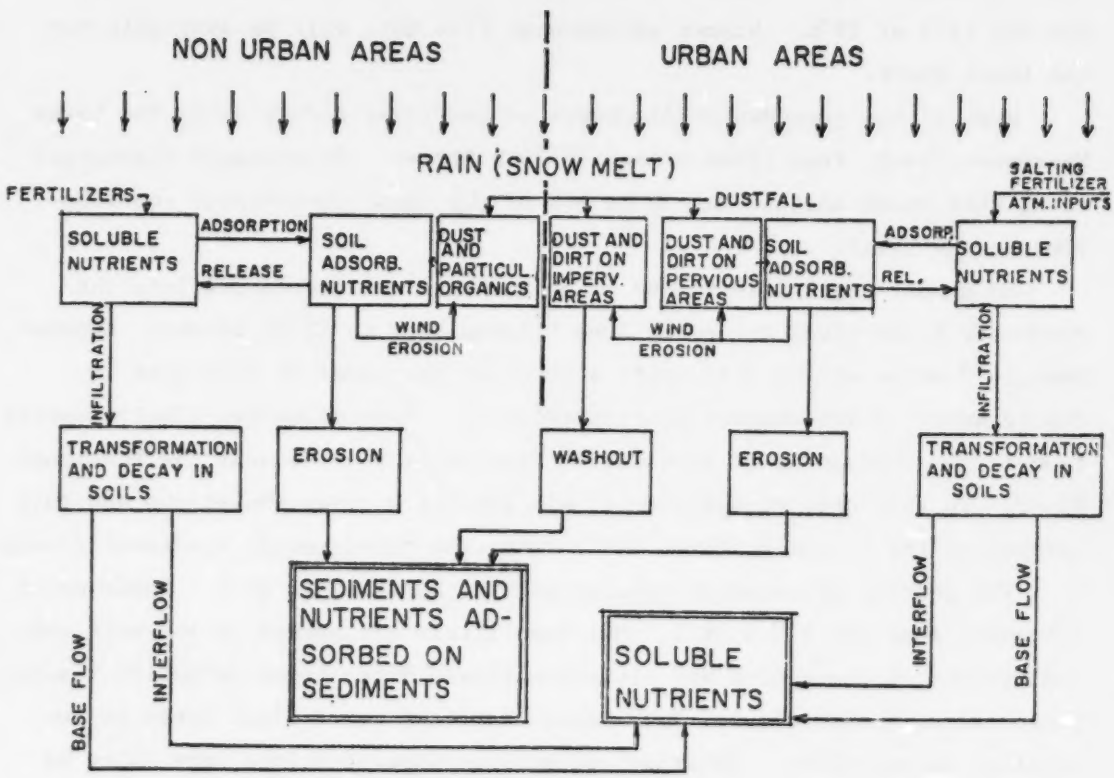

Fig. 5. Schematic conceptual flow diagram of the LANDRUN model.

B. GROUNDWATER

Groundwater discharges to the Menomonee River accounted for 50% of the base flow during the fall of 1977, 65% of the base flow during the winter of 1976-77, and 35% of the base flow during the spring of 1977. The groundwater contribution to base flow in the river is shown in Fig. 6 for the fall of 1976. Summer groundwater flow data will be available for the final draft.

Most of the groundwater discharge to the river occurs along the Lower Menomonee River, from 124th Street to 70th Street. Groundwater discharges along this reach account for 50 to 65% of the total groundwater contribution to the river.

An almost negligible volume of groundwater was discharged into the Menomonee River along the reach from Pilgrim Road to 124th Street. Approximately 3 miles of the 5 1/2 mile stretch of the river in this area is losing water to the shallow aquifer (Fig. 6). This situation likely results from large withdrawals of groundwater from wells located near the Menomonee River. In this area groundwater levels are below river elevations and this portion of the stream receives discharges from three sewage treatment plants.

The general groundwater quality within the basin is good. Toxic metal concentrations are < 0.1 µg/l. Nutrient levels are generally low with concentrations of phosphorus and nitrate-nitrogen often below detection limits. Bacterial contamination was found where sanitary sewer lines cross or run parallel to the river. Chloride and sulfate concentrations were twice as high in groundwater as in the surface baseflow water for the lower part of the watershed.

The loading rates of groundwater to the river for the fall of 1976 are presented in Table 23. The loading rates for all seasons monitored will be compiled for the final draft. The river reach from Station 683001 to 413005 had the largest groundwater loading rates to the river for all parameters. The relative importance of the groundwater loading to the river baseflow loading will be determined after river baseflow loadings are available. The groundwater contribution during most events is considered to be insignificant.

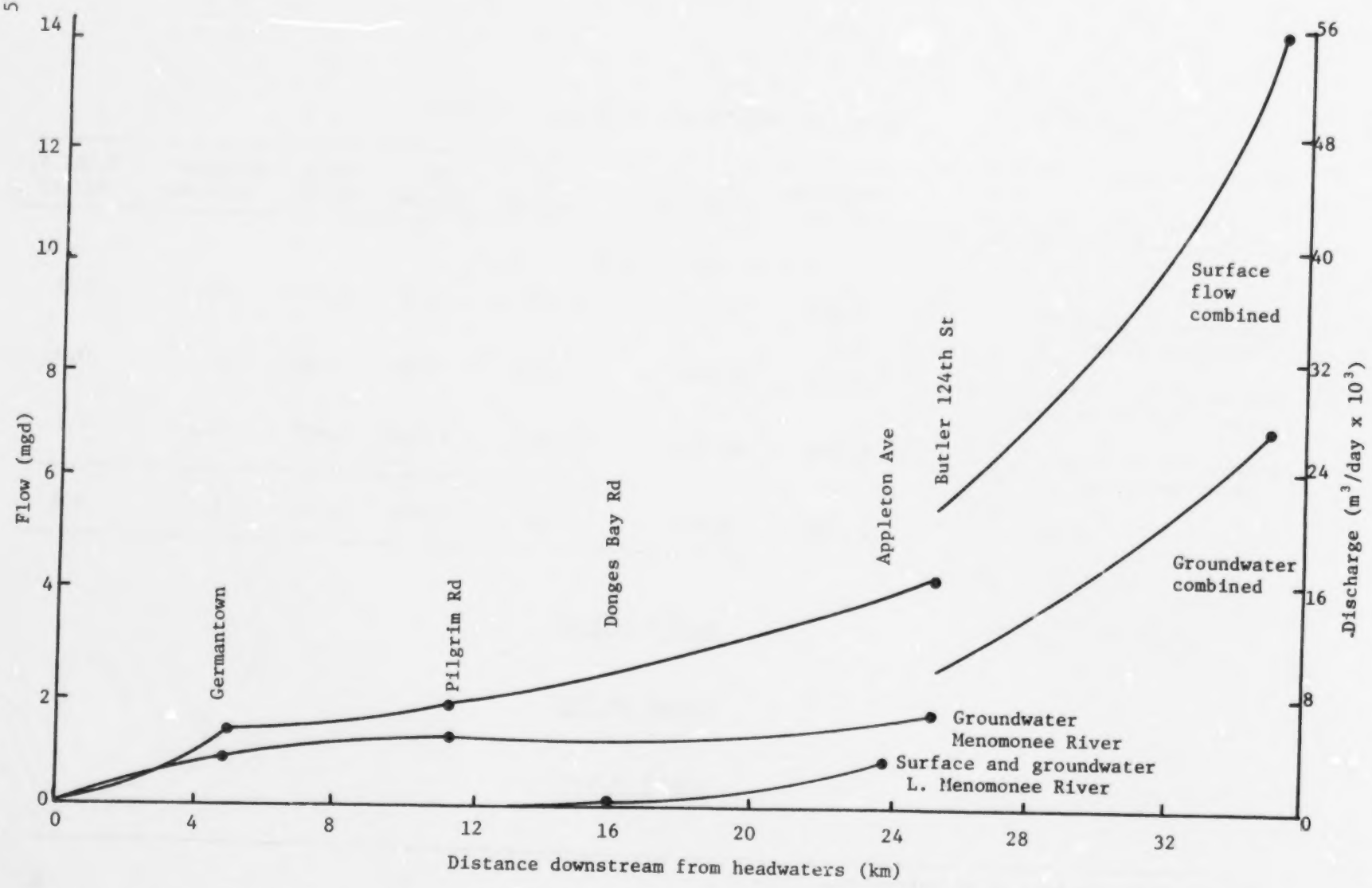

Fig. 6. Groundwater and surface water discharges for the Menomonee River watershed in the fall 1976.

Table 23. Groundwater loadings in 1976-77.*

Reach	Discharge, m^3/day	Dissolved solids, kg/day	SO_4 kg/day	Cl kg/day	$CaCO_3$ kg/day	Dissolved P, kg/day	Total N, kg/day
		FALL OF 1976					
Germantown to Butler (Menomonee River)	5,000	4,450	660	1,250	1,950	0.2	1.8
Donges Bay Rd. to Appleton Ave. (Little Monomonee River)	3,500	2,600	420	450	950	0	0.9
Butler to 70th Street (Menonomee River)	16,500	28,800	5,040	5,550	6,850	1.2	7.1
TOTAL	25,000	35,850	6,120	7,250	9,750	1.4	9.8
		WINTER OF 1977					
		SPRING OF 1977					
		SUMMER OF 1977					

*Blanks indicate data to be calculated.

A model which simulates the transport of conservative ions such as chloride and nitrate through a one-dimensional groundwater system is currently being tested. It will be used to model the movement of chloride in several vertically oriented cross sections. Field data suggest that chloride concentrations in groundwater appear to be directly related to land use loading rates while concentrations of other ions are either relatively low or not directly related to land use patterns. Therefore, attention will be confined to modeling chloride concentrations. Simulated concentrations will be compared with field measurements. Instructions will be presented for applying the model to other watersheds.

In order to relate groundwater quality to land use, a series of land use/groundwater contaminant potential maps are being prepared. These maps note the locations of industrial, agricultural and residential activities which may affect ground and receiving surface water quality. Information on the surrounding geologic and hydrologic settings and the history of operations at these sites was developed as was a methodology to rank contaminant potentials between sites.

The contaminant potential sheets currently being prepared fit in the following categories:

1. Existing areas of high, medium and low density septic tank use.
2. Areas of septic tank use projected for the year 2000.
3. Solid waste disposal areas that have been active for the last 25 years.
4. Miscellaneous waste processing facilities; industrial waste water disposal, sewage sludge spreading sites, possible sewer line leakage zones.
5. Current agricultural cropland areas.
6. Agricultural cropland areas projected for the year 2000.
7. Animal feedlot areas.
8. Liquid and solids storage and transport; metal salvage yards, road salt storage areas, oil terminals, pipelines, rail yards, etc.
9. Highway and street runoff areas.
10. Residential lawns.

A table which will summarize information on groundwater quality as related to land use will be prepared for the final report.

C. ATMOSPHERIC MONITORING

The Menomonee River watershed is characterized by five major land use types: heavy industrial, residential, transition-urban, mixed rural and rural. Suspended particulate and rain samplers were located in each of these areas to elucidate local effects on air pollutant levels (Fig. 1).

Average total suspended particulate concentrations can be ranked by station from highest to lowest: Falk Corp. (413004), 70th St. (413005), Appleton Ave. (413008), River Lane (673001) and Donges Bay (463001) corresponding to the above listing of land use types (Table 24). In a distance of less than 15 miles the total suspended load decreases by 50% from Falk Corp. (413004) to Donges Bay (463001). However, concentrations measured at Donges Bay (463001) are undoubtedly influenced by the proximity of local urban emission sources during certain wind conditions. The average background level of suspended particulate matter for this area is thought to be 40 $\mu g/m^3$.

All stations exhibit similar trends in the suspended load from one sampling interval to the next. This is even true for the two most distant stations; Falk Corp. (413004) and River Lane (673001) (Fig. 1). A combination of two phenomena contribute to the region-wide trends. Large air masses, with a characteristic pollutant load, influence background suspended concentrations at all the stations. Of equal importance are meteorological conditions affecting the dispersion of pollutants across the whole watershed. The high concentrations observed at Falk Corp. (413004) are quite obviously of local origin. In addition, local mixing height and wind conditions play a major role in the observed temporal trends.

Suspended dust concentrations in themselves are of importance for human health reasons. For assessing the impact of airborne pollutants on water quality, deposition calculations must be made. Of the heavy metals and nutrients studied in this project, only lead and possibly phosphorus have significant atmospheric inputs to the watershed relative to weathering and point sources at the surface.

Rain samplers allow measurement of concentration and hence direct calculation of input for lead and phosphorus. Table 25 lists the mean concentrations in rain for several constituents including lead and phosphorus. Dry deposition is a function of suspended concentration and deposition velocity of the particles. For lead this velocity is about

Table 24. Ranking* of stations by total suspended particulate concentrations, $\mu g/m^3$

Falk Corp. (413004)	>	70th St. (413005)	>	Appleton Ave. (413008)	>	River Lane (673001)	>	Donges Bay (463001)
87.2		—		—		51.3		44.0

*The relationship holds true for 23 sampling intervals; not all stations had data for same intervals.

Table 25. Mean* concentrations in rain for several constituents, ppb

PB	P	Na	Ca	Mg	Cd
32	13.6	120	800	280	3.74

*Mean concentrations of all data from all stations.

0.1 cm/sec (Dovland and Eliasson, 1976). A value for particles containing phosphorus is uncertain.

Based on a mean concentration of 30 µg/l and an annual precipitation total of 30 inches, lead loading to the watershed by rain alone is calculated to be 230 g/ha/yr. The dry deposition rate for lead is approximately 180 g/ha/yr based on these studies and those of Hudson et al. (1975) and Andren et al. (1977). Overall, lead enters the watershed via the atmosphere at a rate just over 400 g/ha/yr or 1.4×10^4 kg/yr.

From the work of Benninger et al. (1975) it is evident that virtually all lead is sequestered by soil particulate matter, precluding any significant dissolved concentrations in the river. Hence, atmospherically derived lead would not be expected to reach the river unless it was deposited on an impervious surface. Approximately 20% of the watershed is impervious (roads, roofs, etc.). During the winter, when the ground is snow-covered and frozen, the percent imperviousness is taken as 100%. With these conventions, a calculation shows that 45% of all deposited lead reaches the river. This is probably an overestimation since many impervious surfaces are not connected. Further, since most of the lead will associate with particulate matter in the river, a very small fraction of atmospheric lead reaches Lake Michigan via the river. This is not to imply that no local problems of high lead concentrations exist. Indeed, in strictly urban land use areas, up to 80% of the surface is impervious. Additionally, these areas are subject to the highest emission rates of lead (from automobile exhaust). Hence, total lead concentrations in street runoff can be extremely high.

Andren, A. W., S. Eisenreich, F. Elder, T. Murphy, M. Sanderson and R. J. Vet. 1977. Atmospheric Loadings to Great Lakes.

Benninger, L. K., D. M. Lewis and K. K. Turekian. 1975. The use of natural Pb-210 as a heavy metal tracer in the river-estuarine system. Marine Chem. in Coastal Environ. pp. 201-210.

Dovland, H. and A. Eliasson. 1976. Dry deposition on a snow surface. Atmos. Environ. 10:783-785.

Hudson, J. L., J. J. Stukel and R. L. Solomon. 1975. Measurement of the ambient lead concentrations in the vicinity of Urbana-Champaign, Illinois. Atmos. Environ. 9:1000-1006.

D. LAND COVER CLASSIFICATION FROM AERIAL IMAGERY

The project is an investigation of the feasibility of interpreting land cover information — obtained by high altitude aerial imagery — for input into the LANDRUN hydrological model. Techniques developed involve digitizing the imagery, calibrating the digital imagery, and classifying the data into a number of land cover classes. The results of the investigation have not been used directly in the model but rather a comparison was made of traditional methods of interpreting land cover with these techniques for application to other urban watersheds in the Great Lakes.

Two sub-watersheds in the Menomonee River basin were chosen to test these techniques, namely, the Schoonmaker and Noyes Creeks sub-watersheds. High altitude imagery (scale 1:120,000) flown by NASA was digitized with a ground resolution of 6 meters square. Land cover was classified in each watershed and compared with human photo-interpretation and data supplied by SEWRPC. A summary of the classified data is:

Landcover	Schoonmaker Cr.	Noyes Cr.
Impervious	63.6%	38.0%
Vegetation	25.4%	50.0%
Forest	0%	3.7%
Transition	10.7%	3.3%
Water	0%	0.05%
Unclassified	0.3%	4.95%
	100%	100%

Since impervious surfaces in urban areas are deemed to be the most important land cover class, the table shows the results for this class. The computer classification included five land cover classes: impervious surfaces, tree cover, crop land, other vegetation and water.

Three other urban watersheds were investigated using this technique. Imagery (scale of 1:130,000) of Detroit-Windsor, Toledo, and Rochester were acquired from the EROS Data Center, Sioux Falls, S.D. In these cases, NASA had not properly calibrated the imagery and the classification accuracy

dropped to 80 to 85% from 95% for the digital classification in the Menomonee watershed. The data have indicated that it is possible to use high altitude imagery to obtain land cover information for other urban watersheds and the technique could be used for land cover classification and modeling of urban watersheds throughout the Great Lakes basin.

E. BIOLOGICAL MONITORING

Macroinvertebrates spend all or part of their life in streams and rivers associated with the bottom sediments. They are sensitive to changes in water quality and can be used as long term in situ indicators of water quality. Diversity indices, describing the macroinvertebrate community structure, have been used to locate municipal/industrial point sources of pollution (Gaufin and Tarzwell, 1956). Gislason (1971) used a diversity index to define an area with point and non-point urban pollution and heavy agricultural pesticide inputs. Hilsenhoff (1977) developed a biotic index to assess water quality by assigning quality values to macroinvertebrates. Diversity and biotic indices were used in this study to differentiate the aquatic populations affected by non-point agricultural and urban pollution.

The major land use activities surrounding each site were determined and stations arranged in order of increasing urbanization (Table 26). The trend of increasing urbanization is generally from upstream to downstream except for Noyes Creek which is an urbanizing area located in the agricultural portion of the Little Menomonee watershed.

Sampling of the macroinvertebrate population was undertaken on November 8-9, 1976 and May 12-13, 1977. Surber samplers were used to collect organisms in riffle areas ranging from upstream agricultural area of the Little Menomonee River (463001) to the urbanized region of the mainstem (413005) (Fig. 7). The May sampling included additional sites at 673001A and 673001.

The November sampling revealed that the Little Menomonee River agricultural sampling site (463001) had the highest diversity value (Table 26). Based on the classification scheme proposed by Wihlm and Dorris (1968), sites with diversity values < 1 are heavily polluted and those > 3 are clean. Thus, site 463001 is the only station that can be considered clean according to these criteria. The next two agricultural sites have patchy deposits of creosote in the sediment (EFA, 1977). In 1973, an attempt was made to remove the creosote-contaminated bottom sediment from site 413011A. The cleanup stopped just before site 413011B. The predominant oligochaete population at 413011A yielded an index value indicating heavy pollution. The increase in diversity further downstream indicates possible recovery but all stations, agricultural and urban, have values which imply moderate pollution. The exception was an urban site (413006B) with a value < 1.

Table 26. Diversity and Biotic Index Values for sampling sites in order of increasing urbanization

STORET number	Location	Urban:Agriculture Ratio	Diversity Index November 1976	Diversity Index May 1977	Biotic Index May 1977
	Agricultural				
673001A	Freistadt Rd. and STH 145	14:86	--**	2.50	3.83
673001	Riverlane Rd., Hwy F	14:86	--**	2.27	4.24
463001	*Donges Bay Rd.	14:86	3.30	1.50	3.83
413011A	*91st and Goodhope Rd.	20:80	0.81	1.20	3.75
413011B	*Mill and Fond du Lac Ave.	34:66	2.79	1.10	4.11
	Urban				
413006A	Above Honey Creek (November sampling 91 meters, May 385 meters)	72:28	1.31	0.13	4.70
413006B	Below Honey Creek (91 meters)	72:28	0.66	1.30	4.70
413005	70th Street Bridge	72:28	1.49	1.20	4.50
413011	*Noyes Creek	74:26	2.07	0.60	4.06
413006	Honey Creek	80:20	1.37	0.00#	0.00#

*Little Menomonee River
**Not sampled in Nov. 1976
#No organisms found

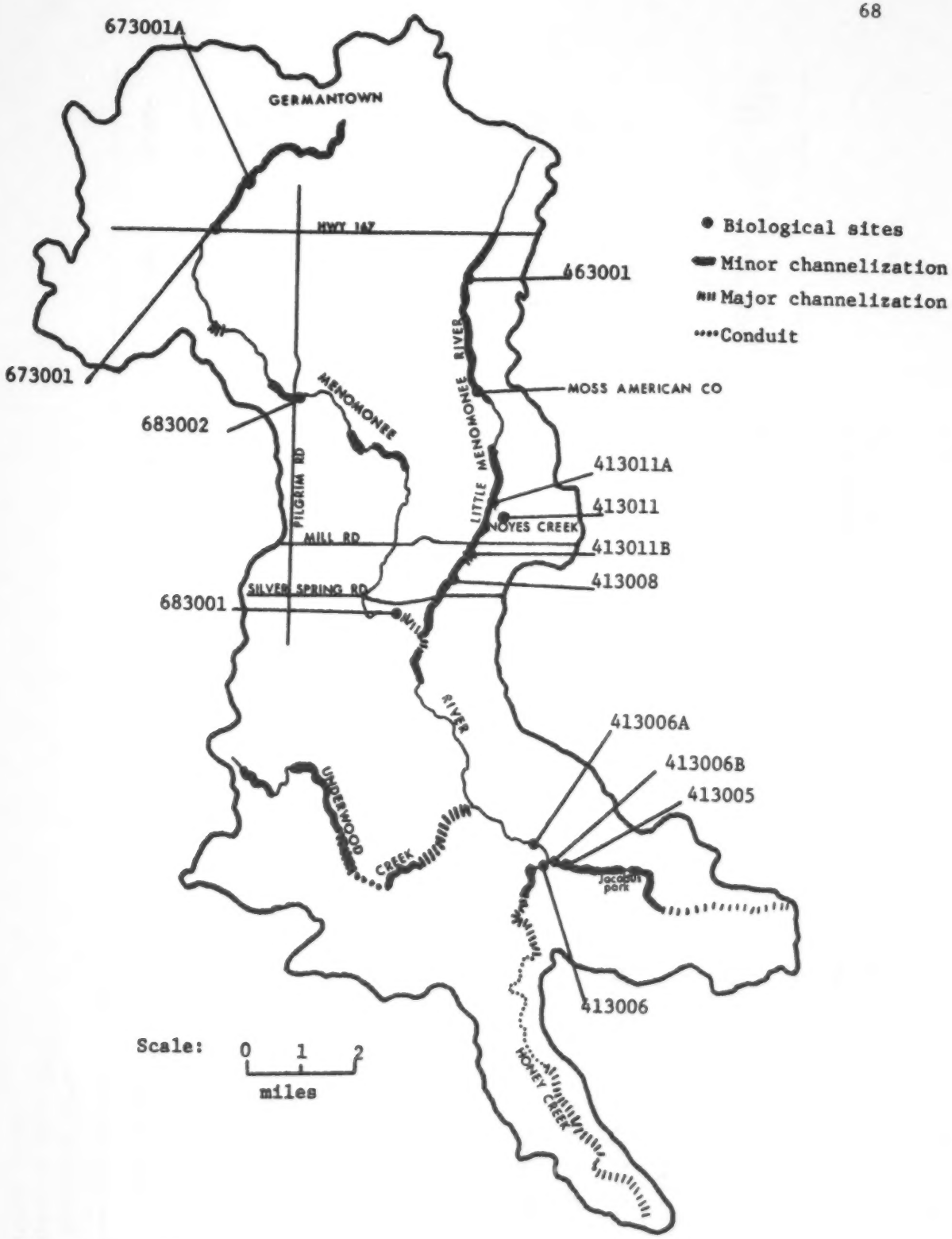

Fig. 7 Menomonee River watershed showing biological monitoring sites and modification of the river channel.

There is a general decrease in the number of macroinvertebrates toward the urban area except for the two tributaries, Noyes Creek and Honey Creek. Noyes Creek contained an extremely high number of isopods and Honey Creek had a large population of oligochaetes. Other than Noyes Creek, in areas of the watershed that were at least 70% urban and/or had a point source of pollution, the samples were 90% oligochaetes, chironomids and gastropods.

The greatest abundance of macroinvertebrates as well as the highest diversity index values were obtained at the northwest Menomonee River agricultural sites during the May sampling. According to Wihlm (1968) these sites are rated as moderately polluted. The uppermost site (673001A) supported Baetis, Hydropsyche and Chironomidae. Below a golf course (673001), the community was predominately Simulium, Dugesia and the pollution tolerant chironomid, Glypotendipes. At the Little Menomonee River upstream agricultural site (463001) half the number of macroinvertebrates were found but its diversity value still placed it in the moderately polluted category. The data shows that Honey Creek (macroinvertebrates absent), Noyes Creek and 413006A are heavily polluted. All other stations were moderately polluted. According to the biotic index, all stations are rated as grossly polluted since index values exceed 3.75.

Since macroinvertebrates were only identified to genera and chironomids, oligochaetes and gastropods were treated as three groups the sensitivity of these indices was impaired. However, even if taxonomic identification had been performed to the species level, relative rating of the stations would likely not be changed.

The diversity and biotic indices can locate areas of disturbance but cannot differentiate specific impacts of major land use categories on macroinvertebrate communities. Due to the relative insensitivity of the indice calculation as applied in this study, values obtained in moderately polluted agricultural areas will be similar to those areas with moderate urban pollution even though the macroinvertebrate genera may be different.

Environmental Protection Agency (EPA). 1977. Impact of creosote deposits in the Little Menomonee River, Wisc. 33012-77-016 National Enforcement Investigations Center. Denver, Colorado. 47 p.

Gaufin, A. R. and C. M. Tarzwell. 1956. Aquatic macroinvertebrate communities as indicators of organic pollution in Lytle Creek. Sewage & Ind. Wastes 28(7):906-924.

Gislason, J. C. 1971. Species diversity of benthic macroinvertebrates in three Michigan streams. Tech. Report No. 20. Institute of Water Research. Michigan State Univ.

Hilsenhoff, W. L. 1977. Use of Arthropods to evaluate water quality in streams. Dept. of Natural Resources. Technical Bulletin No. 100.

Wilhm, J. L. and T. C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience 18:477-481.

12. RELATIONSHIP TO PLUARG OBJECTIVES

The program developed by PLUARG is designed to assess pollutional loadings to the Great Lakes including their magnitude, source and effect on the water quality of the lakes. This assessment must eventually provide recommendations of technically-feasible, cost-effective remedial management alternatives for land-derived pollution control. The pilot watershed studies were designed to allow detailed monitoring of all major land uses in the Great Lakes basin. The Menomonee River Pilot Watershed Study deals with those land uses in a highly developed urban setting (southern part of the watershed) and in a rapidly urbanizing area (northern part of the watershed).

Methodology has been developed in the Menomonee study which permits extrapolation to each of the municipal centers in the Great Lakes basin. Presently, tests are being conducted on the Toledo watershed to determine what amendments to the model must be made for different geographical regions. Primary information about the watersheds that is needed to conduct assessments are: land use, topography, climatological and some water quality data. Methods to determine land use and degree (%) of imperviousness in an urban area by remote sensing have been developed in the Menomonee and tested satisfactorily in the Detroit, Rochester and Toledo areas. Furthermore, the predictability of the LANDRUN model based on extrapolation of unit area loads for one urban and two agricultural watersheds (1,000 to 1,800 ha in size) in the Canadian Grand River watershed will be used to test transferability and extrapolation of the Menomonee River watershed data and methodology and will be compared to loadings obtained from monitoring data.

Simulated unit area loadings have been developed for 12 land uses and a relative hazard scale was established. Since the hazard scale was developed logarithmically — i.e., a land use with a hazard scale of 2 has a tenfold greater unit area load than a land use of scale 1 — it should be applicable to the entire Great Lakes basin. Thus, it would be possible to define the minimum area to be treated in a watershed to achieve a predetermined reduction in loading. Furthermore, point source loadings could be superimposed on these calculations so that for a series of reductions in point sources (e.g., 25, 50 and 75%), the amount of reduction in dispersed

source loadings could be calculated to achieve particular percentage reductions in total load at the river mouth. The impact of reductions in the river mouth loadings required to impact on Great Lakes water quality must be assessed. This assessment should take into consideration that pollutant loadings for different parameters are not closely correlated with one another and decisions will have to be made not only quantitatively but also qualitatively — i.e., to what extent should an attempt be made to reduce each particular pollutant. For example, if a reduction of 40 to 50% in suspended sediment and total phosphorus could be made merely by treating construction sites, industrial manufacturing and extractive areas and high density feedlots (5% of land area), one would then have to make decisions on reductions in river mouth loadings of lead since treatment of the 5% of the land area would achieve only a 3% reduction in lead loadings.

13. REMEDIAL MEASURES RECOMMENDATIONS

1. Qualitative recommendations for the Menomonee River basin

In the Menomonee River basin, two major rural sources of suspended solids and phosphorous, amenable to cost effective pollutant reduction measures, are feedlots and row crops.

Control measures in the urban and urbanizing areas can be directed at either preventing pollutants from entering stormwater, removing pollutants that have entered stormwater, or reducing the amount of stormwater and hence the associated pollutants. Where desired, the selection and application of appropriate techniques depends largely upon hydrologic considerations, i.e., whether the area is serviced by combined or separate sewers or natural drainageways, or if it is in a state of development.

Developed urban areas

In areas with separate storm sewers, the costs of stormwater collection and treatment, or of reducing surface runoff are likely to be prohibitive. Consequently, best management practices are likely those that prevent pollutants from entering stormwater. Alternative methods of stormwater improvement are as follows:

Street sweeping, because of the high costs involved, the rapid build-up of street surface contaminants following sweeping and the poor removal efficiencies of the highly contaminated smaller particles, does not appear to be a cost effective method of improving runoff quality. It is more effective and appropriate however for spring cleanup and during spring seed fall and autumn leaf drop.

High levels of chlorides in winter runoff can be reduced through limited salt application, prewetting with liquid calcium chloride, and adequate covering of stockpiles. A reduced salting program however will likely require the increased use of abrasives.

The increased volume and peak flow of runoff that occurs with urbanization often causes streambank erosion. This may be a significant source of sediment in streams and can be curtailed.

Surfaces readily eroded by wind or water, such as unpaved parking areas, stock piles, loaded dump trucks, etc., can be surfaced or covered to prevent washoff or wind erosion and subsequent deposition.

Significant contributions can be effected by the discreet actions of

individuals if they are aware of how their actions affect water quality. To this end, an informational program can be pursued at low relative costs. An additional benefit of such a program would be the generation of support for wider scale public programs. Local public officials and professionals could also be identified for programs of different levels of sophistication.

In combined sewered areas, federal mandates require comprehensive controls of combined sewer overflows. Generally, some form of storage and treatment appears preferable to sewer separation. In the interim, while awaiting the implementation of such a program, several strategies in addition to those above may be applicable.

Dry weather street flushing can transport street surface contaminants to local treatment facilities. Dry weather sewer flushing may dislodge line deposits, thus allowing for their treatment, otherwise, deposits are likely to be flushed by stormflows and discharged in overflow. Where overflow regulators are in need of replacement, special concentrating devices can direct a heavily concentrated flow to treatment facilities while discharging a less concentrated flow.

Developing and redeveloping areas

A principle concern in construction areas is adequate erosion and sediment control. Although theoritical controls of 90 - 99% are possible, actual applications are typically somewhat less efficient. Again it is the small, heavily polluted particles that are not apt to be controlled. While the costs of erosion and sediment control would likely be internalized by the developer or buyer, in the absence of such controls, the costs would be externalized to the community.

It is in developing and redeveloping areas that the third approach to stormwater pollution control finds its full potential. A high correlation exists between the amount of connected impervious area, the amount of runoff and the pollutant load generated. Rather than trying to remove stormwater as quickly and efficiently as possible, an emerging approach to stormwater management seeks to maximize infiltration and to delay the surge of runoff, spreading it over a longer period of time. The reduction in the amount of runoff will reduce the resultant generation of pollutants, erosion of streambanks and downstream flooding. Peak flow reduction will minimize the necessary carrying capacities of the stormwater conduits, and resultant streambank erosion and downstream flooding.

ii. Quantitive recommendations for the Menomonee River basin

Based of Land-Run derived unit loads and 1975 land use data, the following loads are generated.

SOURCE	S.S. (kg/yr)	% OF TOTAL	T.P.(kg/yr)	% OF TOTAL
Point Sources	90,500	1	13,800	47.7
Development	4,000,000	33.1	7,201	24.9
Row Crops	1,612,000	13.3	2,899	10.0
Feedlots	223,000	1.8	800	2.8
Other	6,130,000	50.8	4,232	14.6
Total	12,055,500	100	28,932	100
25%	3,013,875		7,233	
40%	4,822,200		11,573	
60%	7,233,300		17,359	

Control Methods

SOURCE	EFFICIENCY		AMT.CONTROLLED (kg/yr)		TOTAL DOLLARS
	S.S.	T.P.	S.S.	T.P.	
Point Sources	--	75%	--	10,350	?
Development *	70%	50%	2,800,000	3,600	2,290,000/yr
Row Crops **	50%	40%	806,000	1,160	181,200/yr
Feedlots ***	100%	100%	223,000	800	360,000 one time
TOTAL REDUCTIONS (kg/yr)			3,584,370	13,882	
% OF TOTAL			35.7%	51%	

TOTAL COSTS = Cost of point sources + $2,290,000/yr + $360,000

* Controls of 916 ha at $2,500/ha, S.S. is a literature value, T.P. an estimate.

** Controls (contour plowing and strip cropping) on 80% of row crops (more than 2% slope) at $25/ha. Acreage and efficiency of S.S. is a SEWRPC figure, T.P. efficiency is an estimate.

*** Controls on all 36 feedlots within 2000 feet of a stream, at $10,000 each.

iii. Qualitative recommendations for the Great Lakes Basin

1. The identification of the pollutant parameters, and of those areas within the lakes where those parameters exert, or will likely exert, a critical impact upon water quality, are prerequisites to any remedial planning.

2. Control management strategies for dispersed pollutional loadings should always be developed to control the pollutant at the point in the system where it exhibits its highest concentration. It is at this point that the cost of treatment will generally be at a minimum.

3. For those parameters identified, an assessment of the contributions of point sources and their probable reductions, coupled with total levels of reductions sought, will indicate the likely degree of non-point reductions needed.

4. Based upon unit loadings and present water quality, large tracks of land in the Great Lakes Basin will require little or no non-point control unless major land use changes occur in the future. At first approximation, these likely include the entire L. Superior basin, most of L. Huron, and significant portions of L. Michigan and L. Ontario.

5. If land derived sediment and phosphorus loadings to L. Erie are generated relatively uniformly over the L. Erie basin, extensive control measures may be warranted.

6. Cost effectiveness of pollution control are generally highest at those locations where or times when pollutants are most concentrated. These typically include point source discharges, construction sites, vehicular emissions, autumn leaf drop, etc....

7. Where non-point reductions are needed to achieve desired water quality, local drainage areas should be assessed for sub-areas within them which are generating significantly higher levels of pollutants. Control within these "hot-spots" will likely return the greatest results for the dollar.

8. Rapid reductions in the use of leaded automobile fuels, as well as improved emission control technology, will nearly eliminate the non-point source lead input into the Great Lakes over the next decade.

9. As high correlations exist between the amount of runoff and associated pollutant loads, efforts to maintain or reduce the amount of runoff will maintain or improve water quality. An awareness of, and appreciation for, this correlation is especially important in the planning of new or redeveloping areas. Here runoff reducing mechanisms can be implemented often at lower costs than conventional drainage systems. Principle design concepts include preservation of natural drainageways, elimination of curb and gutter systems, use of infiltration wells and ditches, maximization of pervious areas, indirect rooftop drainage, etc....

10. Public awareness of the causes and effects of, and control alternatives for, non-point pollution is essential to the success of any control program. To assure this, an informational/educational program is necessary. Not only should lay citizenry be targeted for such, but also public officials and related professionals. Each facet of the program should be developed with a format and level of sophistication appropriate for each target audience.

11. Thousands of new and exotic chemicals are developed yearly, many of which are discharged into surface waters. The unforeseen impacts of one of these may be swift, disastrous and long term. Witness the case of PCB's.

It is becoming increasingly more important to improve those mechanisms that guard against further occurrences. A twofold approach is suggested, both to strengthen and upgrade the scientific components of monitoring and analysis, and also to facilitate the resultant institutional response. The speed with which the latter process reacts will likely determine the criticality, severity and eventual effectiveness of control measures. Those agencies with control responsibility should be empowered to react promptly to problems that arise.